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Date: 14 July 1995

**SPACE STATION WATER PROCESSOR
MOSTLY LIQUID SEPARATOR
(MLS)**

Final Report

for

Ion Electronics

Contract # NAS8-38250-12

Prepared By

**UNITED TECHNOLOGIES CORPORATION
HAMILTON STANDARD SPACE SYTEMS
INTERNATIONAL INC.**

Windsor Locks, CT 06096

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2. Abstract

This report presents the results of the development testing conducted under this contract to the Space Station Water Processor (WP) Mostly Liquid Separator (MLS). The MLS units built and modified during this testing demonstrated acceptable air/water separation results in a variety of water conditions with inlet flow rates ranging from 60 - 960 LB/hr.

3. Summary

Prior to the testing described in this report, a prototype MLS was evaluated at HSSSI during the period from the 2nd quarter of 1990 to the 3rd quarter of 1992. Based upon the favorable results of that effort, the current effort was undertaken to further develop the MLS' technology. The current program, which began in March 1994 and concluded in July 1995, was undertaken with the objective of developing the next generation MLS for the requirements of the International Space Station Water Processor (ISS WP). A new MLS design was created that was sized to operate over the full 60 to 960 lb/hr inlet flow range and that utilized an improved control mechanism to regulate gas venting. MLS units were built and tested to demonstrate acceptable performance at higher inlet flow rates (up to 960 lb/hr), under a variety of water conditions. The use of development MLS units made out of translucent plastic material was instrumental in the success of this development program. Performance mapping indicated that acceptable performance can be achieved at 1900 RPM for any water condition with 0% - 14% air in the inlet stream. Several hardware modifications were made during the course of the program to improve performance, the majority of which were successful. Test results suggest that maintaining a near-constant backpressure and RPM within the MLS is of prime importance in providing acceptable performance. Further development effort is recommended.

4. Introduction

The MLS, item 4703, is an integral component in the Waste Water Orbital Replacement Unit (WWORU). The function of the WWORU is to convert a waste water stream into potable quality water. Waste water contains free gas along with many other materials which are prone to foaming. This gas is problematic to the water processor. If it is not removed, performance of the system can degrade significantly. This ORU is described further in Appendix II: MLS Plan of Test on page 59. The MLS is responsible for removing the free gas from the waste water stream. Waste water, upon entering the system inlet, flows immediately through the Mostly Liquid Separator where free gas is separated, collected and vented to the cabin, while the waste water is delivered to storage or is drawn by the process pump into the processor.

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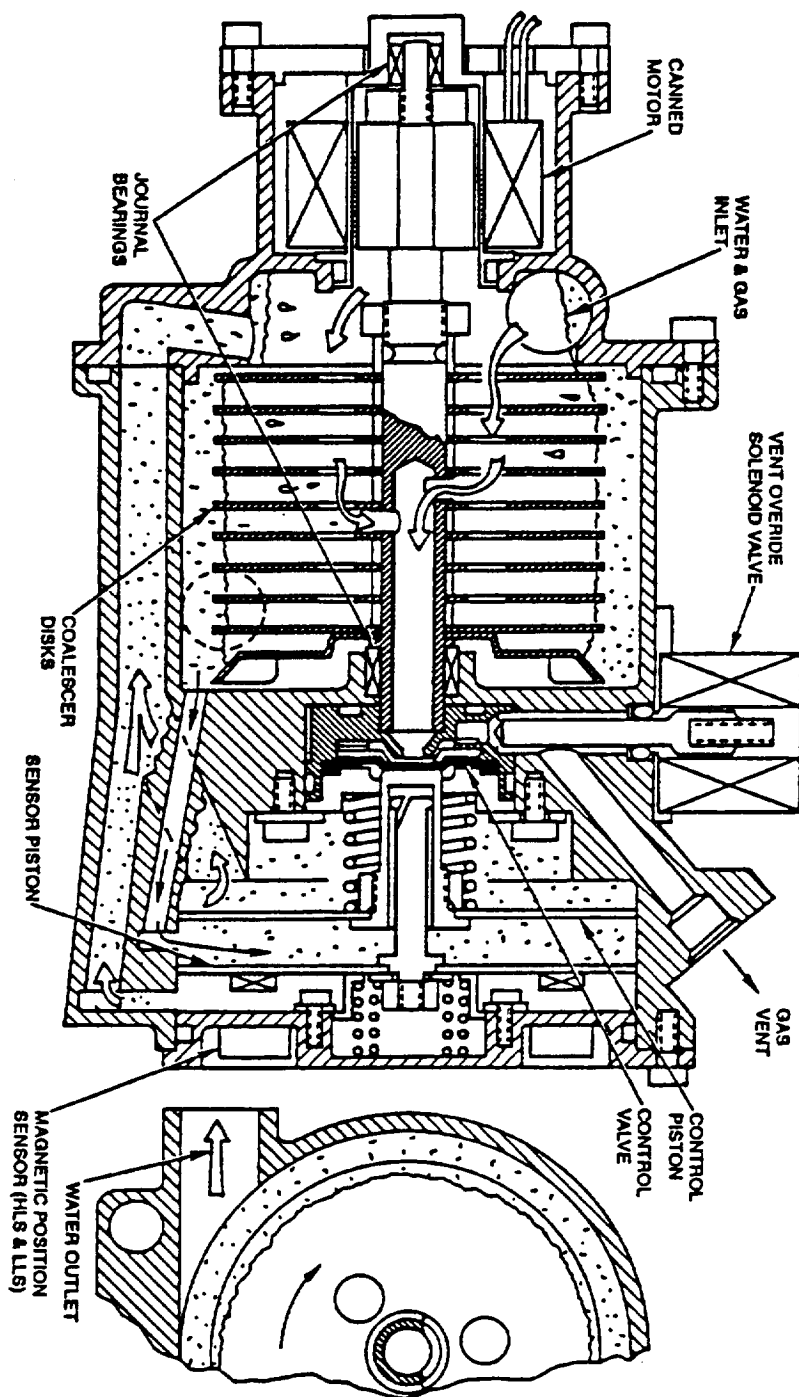


Figure 4-1: MLS Cross Section

Figure 4-1 shows a cross section of the flight configuration of the MLS. The prototype MLS units built and tested contained all of the features of the flight unit except for a flight-style motor, which was replaced with a variable speed, external, direct drive motor.

The motor spins a hollow center shaft mounted on journal bearings. A series of disks are attached to the shaft extending radially outward to a diameter that is about 1/4 inch from the inside diameter of a cylindrical housing. Each disk has a series of slotted holes extending through the disk near its center. The shaft has slots cut into its OD so that the space between some of the disks near the center of the stack is vented to the center of the shaft. The end of the shaft is open to a level control valve arrangement that connects to the gas vent.

In operation, a mixture of water and air enter the unit tangentially at a point near the motor end of the housing. This mixture is forced to spin around the housing centerline as it follows the cylindrical housing wall. Initial separation occurs in this portion of the housing with the water moving to the outside and the air bubbles moving toward the centerline. The partially separated mixture then enters the disk portion of the housing where the centrifugal action of the spinning disks forces the water to the housing wall, forming a water ring that is maintained in motion by contact with the outer edge of the spinning disks. The air moves to the center line and flows through the holes in the disks towards the slots that connect to the center of the shaft. As the control valve opens, gas is vented from the separator. The water moves along the outer wall of the housing and exits tangentially, allowing recovery of some pressure head. Water level in the water ring is maintained by the action of the control valve. A control piston pushes on the control valve element with a force that is proportional to the height and spinning velocity of the water ring. As the water level increases, the static pressure at the outer diameter increases with respect to the centerline pressure due to increased depth and due to an increased rotational velocity resulting from greater contact area on the rotating disks. This difference in pressure creates the level control force and is balanced against a spring to determine the vent valve position.

This report describes the test results, conclusions and recommendations for future action after having built and tested the MLS units developed and modified under this contract.

The MLS is covered under US Patent # 5,244,479 titled Liquid/Gas Separator for Soapy Liquid, dated September 14, 1993.

5. Objective

The overall program objective was to develop the next generation MLS for the requirements of the ISS WP. These requirements are described in Appendix I: MLS Mini-Specification on page 56. The program was subdivided into a Design/Fabrication phase and a Test phase, and the overall program schedule is shown below in Figure 5-1: Program Schedule. The current MLS design was created to fulfill these requirements. Plastic and metal MLS units were fabricated; the plastic units would allow visual observation of the MLS while operating, and the metal units would more closely represent the material choices used in the actual flight hardware. The plastic MLS was used during development testing, and the metal unit was used during an extended performance evaluation.

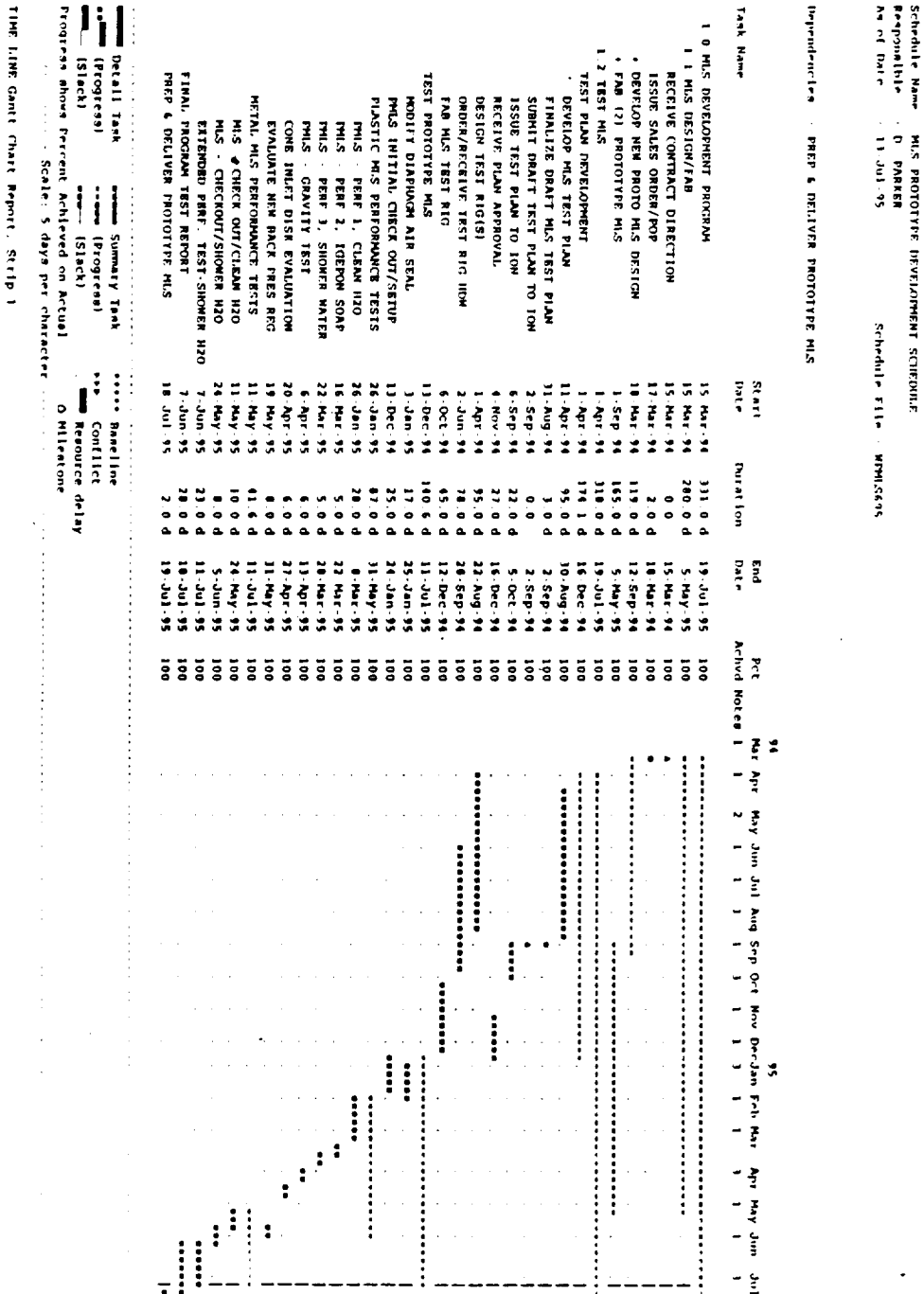


Figure S-1: Program Schedule

Plans of Test were generated to further define test objectives. As stated in the Plan of Test (see Appendix II: MLS Plan of Test), there were four main objectives to the development testing conducted under this contract:

- To map the performance of the MLS within the expected operating conditions of the Space Station Water Processor. This effort first focused on identifying the lowest RPM at which the separator would operate without water carry over into the gas outlet line for the full range of inlet flow rates. As the MLS is designed to operate with a constant RPM, the lowest possible RPM suitable for all flow rates would then be selected as the operating value. It was believed that minimizing the RPM would lower power consumption and minimize any detrimental turbulence within the MLS. Using this RPM, the amount of air carried-over in the water outlet lines was measured for each inlet flow rate and for various percentages of air in the inlet stream. This performance mapping procedure was repeated using clean water, soap and water, and shower water.
- To demonstrate the insensitivity of the MLS unit to gravity. This was accomplished by orienting the MLS in various positions and then mapping its performance.
- To identify potential enhancements to the design or operation of the MLS. Observations made during development testing resulted in frequent modifications to the MLS and test rig.
- To evaluate the extended performance characteristics of the separator. During the course of this effort, a supplementary document was created to further define the extended performance testing. See Appendix III: MLS Extended Performance Test Plan.

6. Description of Test

As stated above, two Test Plans (see Appendix II: MLS Plan of Test on page 59 and Appendix III: MLS Extended Performance Test Plan on page 75) were created to specify the test objectives for this program. The primary purpose of the MLS tests were to further develop the MLS technology, characterize its performance and define its operating requirements. Due to the developmental nature of the program, modifications to the test rig and to the MLS were frequently made to help improve and verify performance. The final configuration of the test rig is shown in Figure 6-1. Appendix IV: Photographs on page 87 shows the test setup. To best understand the knowledge learned in this program, a chronological summary of test observations, conclusions and actions is presented.

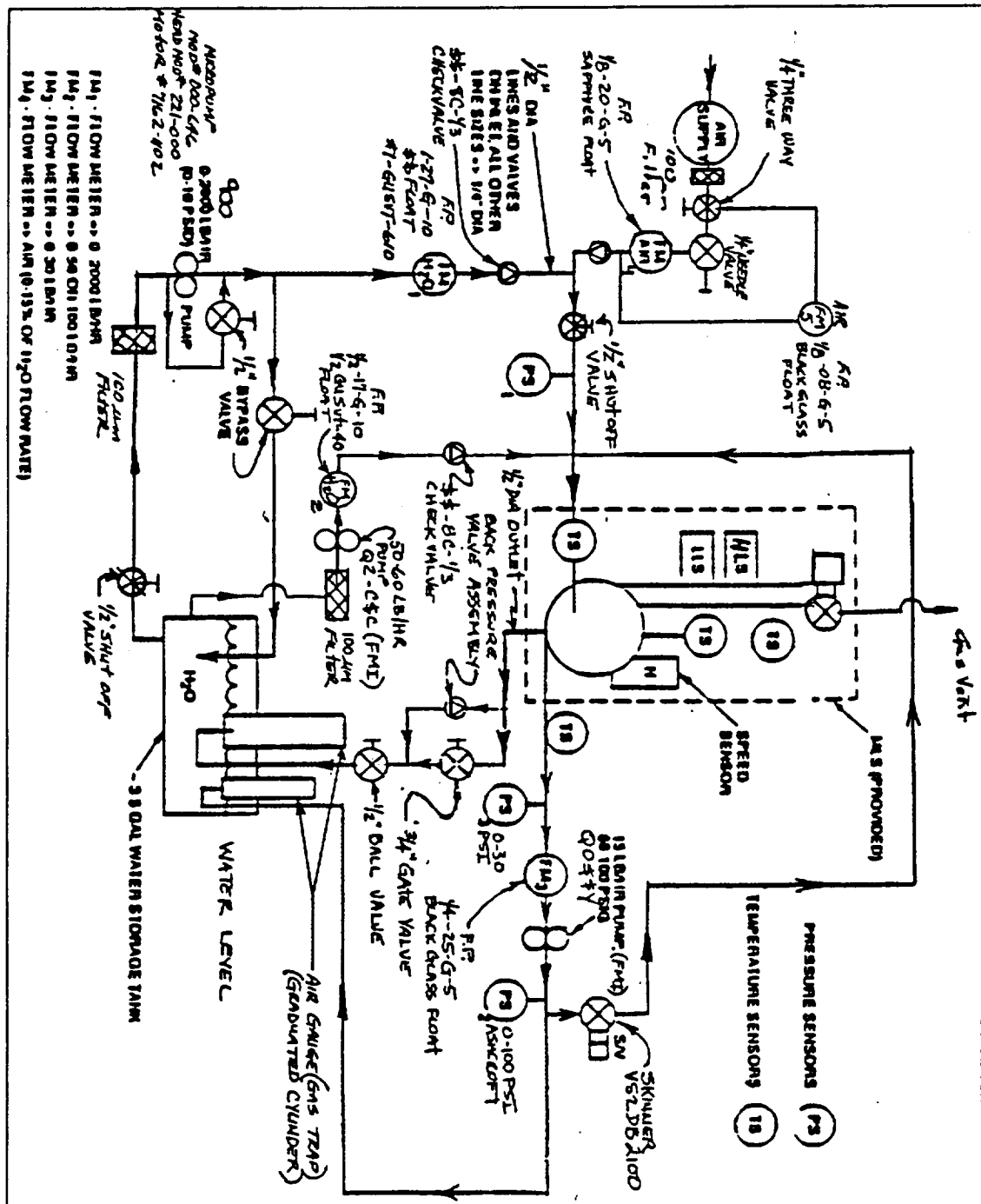


Figure 6-1: Test Rig Schematic

6.1 Clean Water

The plastic MLS unit was assembled and testing began using distilled water. A summary of this phase of testing follows:

6.1.1 TEST PERIOD: Dec 19, 1994 - Jan 26, 1995

SUMMARY:

During initial operation, which followed the device checkout, excessive water carryover was noted. The problem was believed to be an improperly operating diaphragm seal. Upon disassembly, visual inspection revealed the diaphragm to be concave. Measurements were taken to measure the force required to "close" the seal. These measurements indicated that 1.8 lb were necessary, but analysis indicated that the control piston could only provide a maximum of 1.5 lb. The deformed seal geometry and the relative inflexibility of the diaphragm were thought to be causing the higher-than-expected required sealing force. The problem was solved by using a .031 inch thick Fluoroelastomer Seal (different material and thinner than the original design). Shimming was added to both compensate for the reduced seal thickness and add .002" of squeeze at both its ID and OD. The SVSK120861-1 Diaphragm Stop Washer was removed and two new parts, the SVSK121874-1 Control Piston Stop and SVSK121873-1 Diaphragm Sleeve were added to help prevent the diaphragm from being deformed from its desired flat shape. These modifications corrected the deformed diaphragm seal problem.

A second finding reached after observing the operation of the MLS at this time was that the backpressure to the MLS needed to be held constant. The single check valve being used downstream of the MLS was too small and was not capable of holding the backpressure steady for all inlet flow rates. It was therefore replaced with a 3/4" gate valve which required pressure regulation by hand. Test runs indicated that 1.25 - 1.50 psi backpressure could be maintained across all flow rates using this new valve.

CONCLUSIONS REACHED AT THAT TIME:

- The Diaphragm Seal needs to be flat and require minimal force to seal.
- The backpressure needs to be held constant for all inlet flow rates. A 3/4 inch gate valve was installed to hand-regulate the backpressure.

6.1.2 TEST PERIOD: Jan 27, 1995 - Feb 1, 1995

SUMMARY:

With the diaphragm seal operating properly, testing next focused on finding the minimum RPM at which water would not carryover in the gas vent line. The procedure used consisted of setting the flow rate with 14% air, turning off the air input (thus trapping an air bubble inside the MLS) and reducing the RPM until water carryover occurred. Using the RPM value obtained, it was verified that no water carryover would occur using a series of inlet air percentages from 0% - 14%. A plot was generated showing the relationship of inlet flow rate to minimum RPM at which the MLS would properly function. Results indicated that higher flow rates required a higher RPM to prevent water carryover. During this testing, it was observed that the gas would sometimes vent continuously, and would sometimes vent at discrete intervals. Discrete venting would result in the backpressure momentarily falling to near 0 psi.



After the water carryover was mapped, testing of the MLS in transient conditions began. Inlet flow rates were changed as quickly as possible (typically 30 - 45 seconds for the complete cycle) from 60 - 100 - 60 lb/hr and from 960 - 60 - 960 lb/hr using 2% and 14% air and several RPM settings. No water carryover problems were noted, but it was at this time that fine air bubbles in the 15 lb/hr water outlet line (called the process line) were sometimes noted. These bubbles were considered to be indicative of excessive air carryover.

CONCLUSIONS REACHED AT THAT TIME:

- Higher flow rates required a higher RPM to prevent water carryover.
- Transient testing demonstrated no water carryover problem.
- Air bubbles in process line and gas venting occurring at discrete times were seen as improper functioning of the MLS unit.

6.1.3 TEST PERIOD: Feb 2, 1995 - Feb 13, 1995

SUMMARY:

Investigated the cause for the air bubbles in the process line. It was theorized that the discrete venting of gas and the process line air bubbles were interrelated. It was observed that the quantity of air in the process line could be diminished or eliminated by a reduction in RPM. Another observation was that a change in the control spring setting could eliminate both the discrete venting mode and also in the observed air in the process line (called air carryover). The air carryover condition was a qualitative determination.

In-house discussions regarding these issues resulted in two opinions. One was to continue making performance maps for the minimum, nominal and maximum spring settings. For each setting and for each flow rate, it was believed that a minimum and maximum RPM would be found, corresponding to the water carryover and air carryover conditions, respectively. It was hoped that a constant RPM could be found at some spring setting that would not cause water nor air carryover at any flow rate. The second idea was that the air in the process line was related to the outlet port locations inside the MLS housing. Since no air was visible in the main water outlet line, it was believed that gravity effects might be causing the air in the process water line. This could be verified easily by reorienting the MLS unit to reposition the process water outlet line in the horizontal plane and the main water outlet line in the vertical plane. Testing was undertaken to explore both ideas.

After mapping the performance with all spring settings, the results indicated that no operating band could be found at either 500 pph or 960 pph inlet flow using the nominal or maximum spring setting. Using the minimum spring setting, air carryover could not be eliminated for all inlet flow rates. Reorienting the MLS did not significantly change the air carryover in the process line.

Further discussions led to the realization that the SVSK120987-1 End Disk needed minor modification to allow proper venting of gas. The disk was modified by changing the vent holes in the disks to slots, thus providing an air passage to previously trapped air in an adjoining cavity of the disk assembly.

A performance map using the modified End Disk and a minimum spring setting was made, but air carryover was still noted. In addition, some minor water carryover was noted at 960 pph flow, and turbulence in the vicinity of the End Disk was observed under certain conditions.



After reviewing this data, it was concluded that further modifications to the End Disk were necessary. A new SVSK120987-1 End Disk was modified by enlarging the vent holes to 5/16 inch diameter and by removing the paddles. The paddles were removed as they were believed to be "pumping" air into the water in conditions where the water/air interface moved towards the outer diameter of the rotating disks. The holes were enlarged as there were concerns that there was too much restriction in allowing the air to move towards the vent holes in the shaft.

Concerns over the fluctuations in the backpressure resumed. It was recognized that hand regulation of backpressure was inadequate, and so it was decided to use both the installed gate valve and the previously installed check valve in parallel. The gate valve would be used to throttle the flow while the check valve would be able to respond to the observed minor pressure fluctuations.

Water carryover performance mapping was conducted using the new End Disk and the gate valve in parallel with the check valve. Visually noted that the air carryover was improved, although not entirely eliminated. However, minor but consistent water carryover was present at inlet flows from 500 pph and up.

It was concluded that the water carryover was most likely due to leakage past the Rulon bearing into which the disk assembly shaft fits. The changes to the End Disk were seen as the likely reason for this new condition, for two reasons. First was the proximity of the enlarged vent holes in the End Disk to the Rulon bearing. As gas was vented, the water ring would be brought closer to the bearing. Second was the elimination of the paddles, which were included into the original design to help compensate for the drag effects the end of the internal chamber would have on the rotating water ring. Their elimination further allowed the water ring to contact the Rulon bearing.

The disk assembly shaft was shortened, chamfered, and polished. A .008 " plastic washer was fitted into the valve seat into which the shaft fits to act as a dynamic seal. Water carryover was eliminated.

CONCLUSIONS REACHED AT THAT TIME:

- The observed air carryover in the process line needed to be eliminated.
- The SVSK120987-1 End Disk needed modifications to remove the paddles and enlarge the vent holes
- The MLS required the addition of a dynamic seal to prevent water carryover past the Rulon bearing.
- The backpressure needed to be held constant for all inlet flow rates. Fluctuations seen in backpressure needed to be eliminated or at least minimized. Modifications were made to the test rig to control backpressure by using a 3/4 inch gate valve in parallel with a check valve.

6.1.4 TEST PERIOD: Feb 14, 1995 - Mar 2, 1995

SUMMARY:

With new rig and MLS modifications in place, the clean water performance mapping was again generated for the minimum, nominal and maximum spring settings. Air carryover condition was a qualitative measurement, and therefore subjectively determined. Curves summarizing the data gathered follow, with descriptions of the major changes made to the MLS and rig.

The Minimum Spring Operating Band is shown in Figure 6-2 below. Note that at 960 pph inlet flow, the curve is plotted using 2% inlet air instead of 14%. This is because 14% air still yielded air carryover at RPMs below those at which water carryover was occurring. Using 2% air, an air carryover RPM above the water carryover RPM could be determined, and this value is therefore plotted.

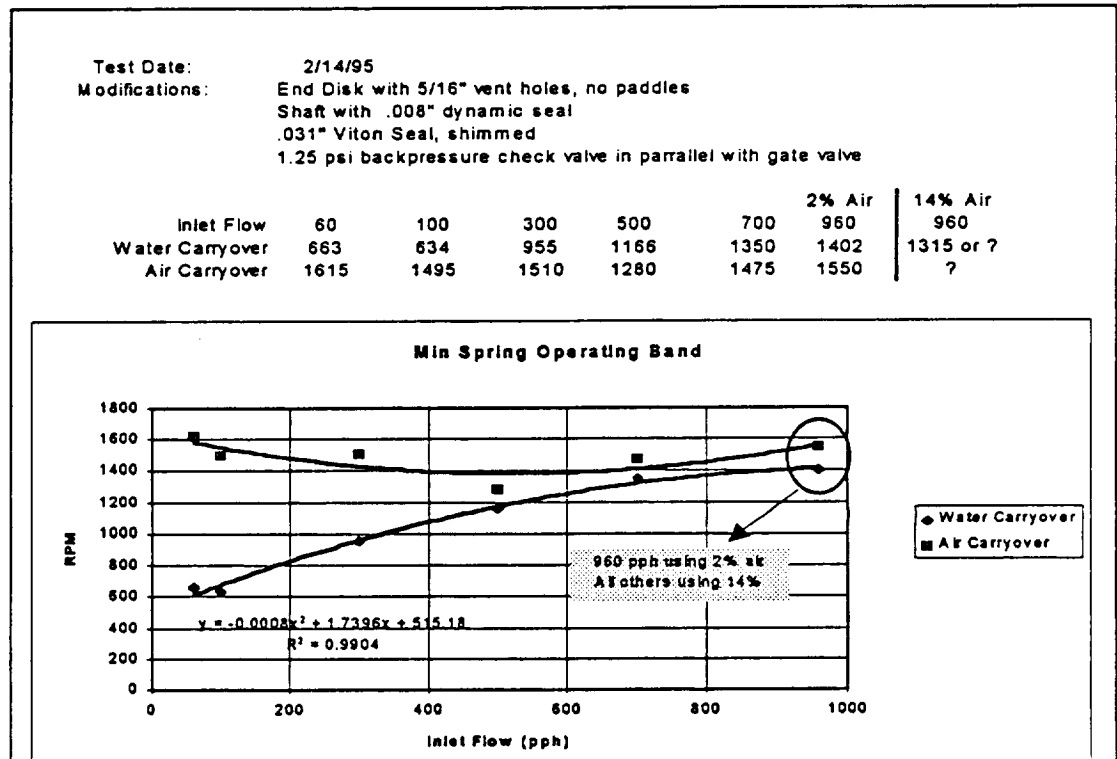


Figure 6-2



The Nominal Spring Operating Band is shown in Figure 6-3 below. Note that at 960 pph inlet flow, the curve is plotted using 2% inlet air instead of 14%, for the same reason as discussed previously.

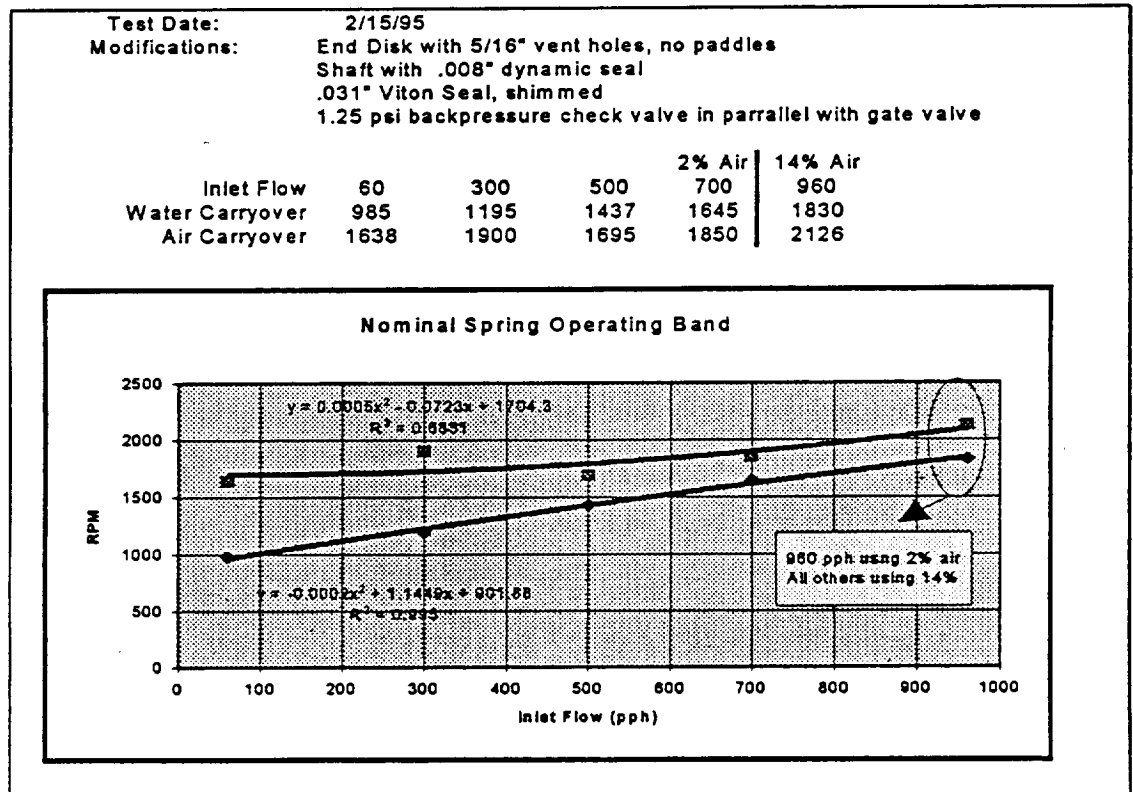


Figure 6-3

The Maximum Spring Operating Band is shown in Figure 6-4 below. Note that at 960 pph inlet flow, the curve is plotted using 14% air for all inlet flow rates.

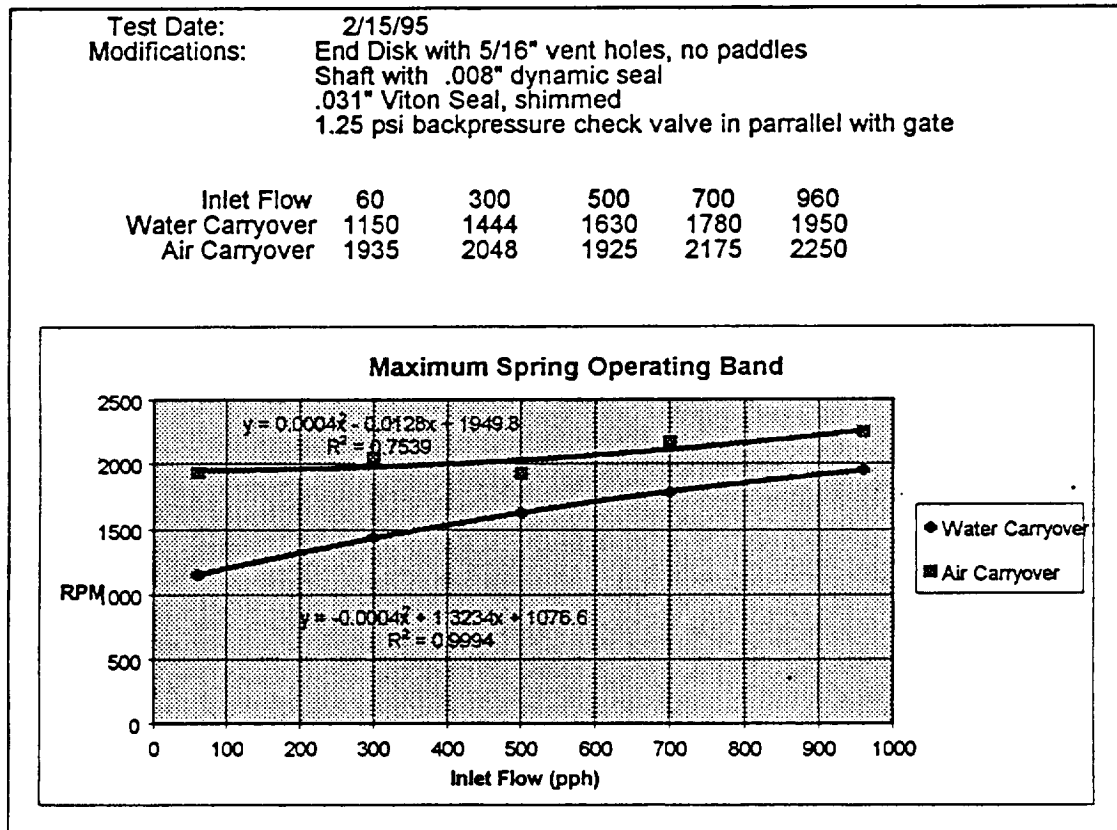


Figure 6-4

These results implied that an operating band existed, but that one could not be found to accommodate the entire 60 - 960 pph range of inlet flows. During a meeting held to discuss these observations, it was agreed that it would be desirable to flatten and/or lower the water carryover curve. If accomplished, this would help to create an operating RPM band in which neither water nor air carryover would occur for any inlet flow. It was theorized that the first disk (inlet side) in the disk assembly might be too close to the housing, thus restricting water flow at the higher flow rates. The first disk (that nearest the inlet) was removed and the nominal spring performance map shown in Figure 6-5 was obtained.

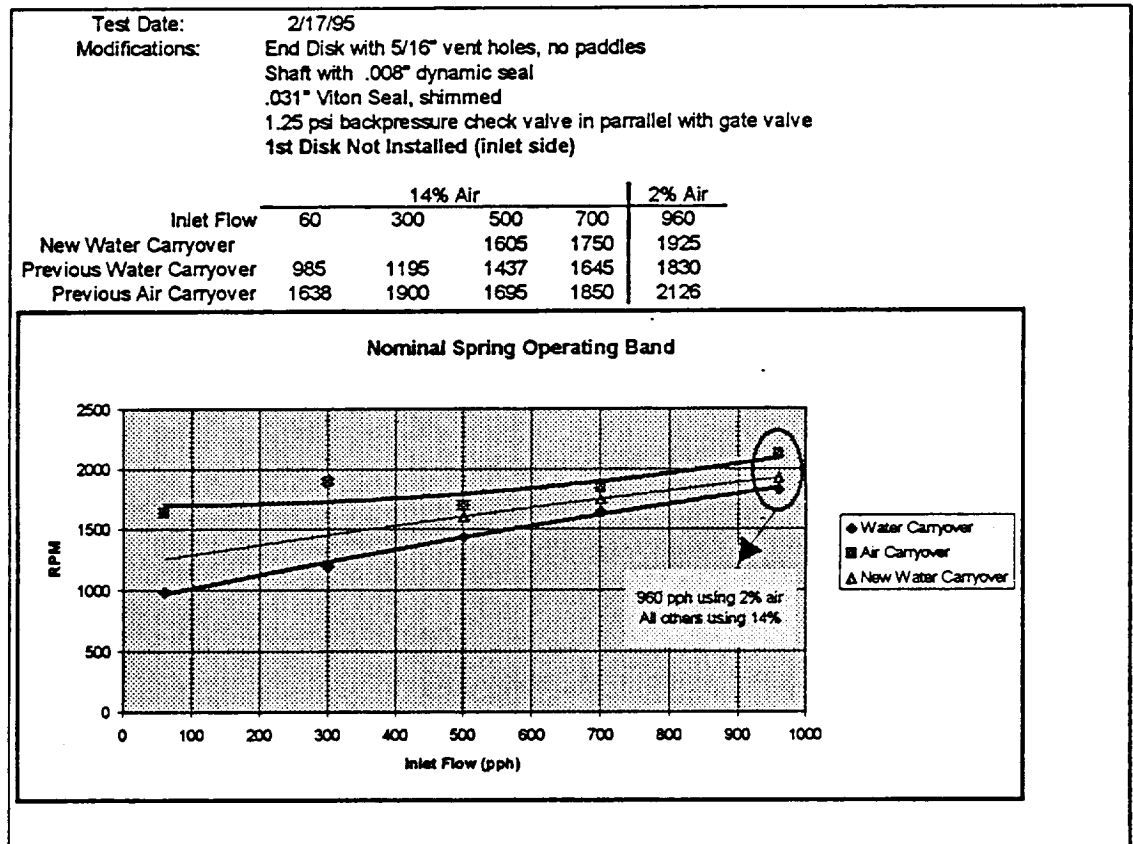


Figure 6-5

Although the water carryover curve got worse, it did seem to parallel the original curve. This observation suggested that not only should the first disk be replaced, but somehow enhanced. This conclusion led us to consider putting an additional End Disk in the first disk position. It would, because of its geometry, provide both additional surface area to help rotate the water ring further (when compared to original flat disk) and provide additional clearance from the housing. Both features were expected to result in a lowering of the water carryover curve.

Several other ideas to improve the MLS performance were discussed at this time. Another idea relating to water carryover was based on the observation that as the RPM is lowered, the rotating water ring collapsed onto the disk assembly shaft at the inlet end first, and then progressed towards the other end. The idea that arose was to move or plug the shaft vent holes nearest the inlet end in order to delay the onset of water carryover.

It was also theorized that an air restriction might be present causing the observed air carryover. It was decided to modify a new set of SVSK120868-1 Disks to change their three vent holes into vent slots, each extending through $\sim 50^\circ$ arc (see Figure 6-6: SVSK120868-1 Disks with Vent Slots). Slots instead of larger holes were desirable as the slots could increase the air flow area while not moving the vent holes any closer to the air/water boundary. It was also decided that

the Shaft be modified to provide two additional vent holes, making it easier for the air to vent into the shaft.

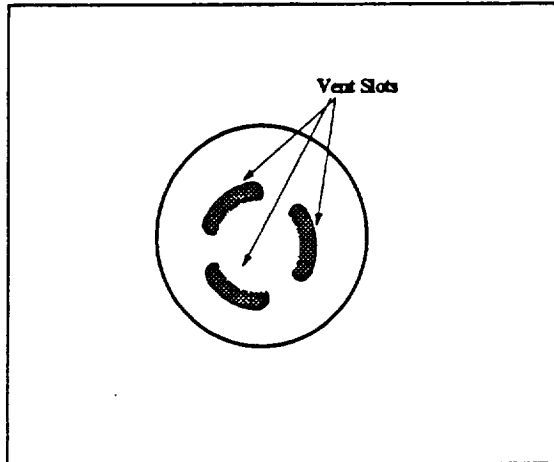


Figure 6-6: SVSK120868-1 Disks with Vent Slots

Several iterations of modifications to the MLS and verification tests took place to verify these ideas. In summary, the addition of an End Disk in the first (or second) disk position, the use of vent slots instead of holes in the disks and the shifting of the shaft's vent holes two disk "positions" away from the inlet (by using the new four vent-hole shaft with the first two holes covered) presented an improvement to the water carryover curve, but not to the air carryover curve, which now had become flatter but also lower in RPM. These results are summarized in Figure 6-7.

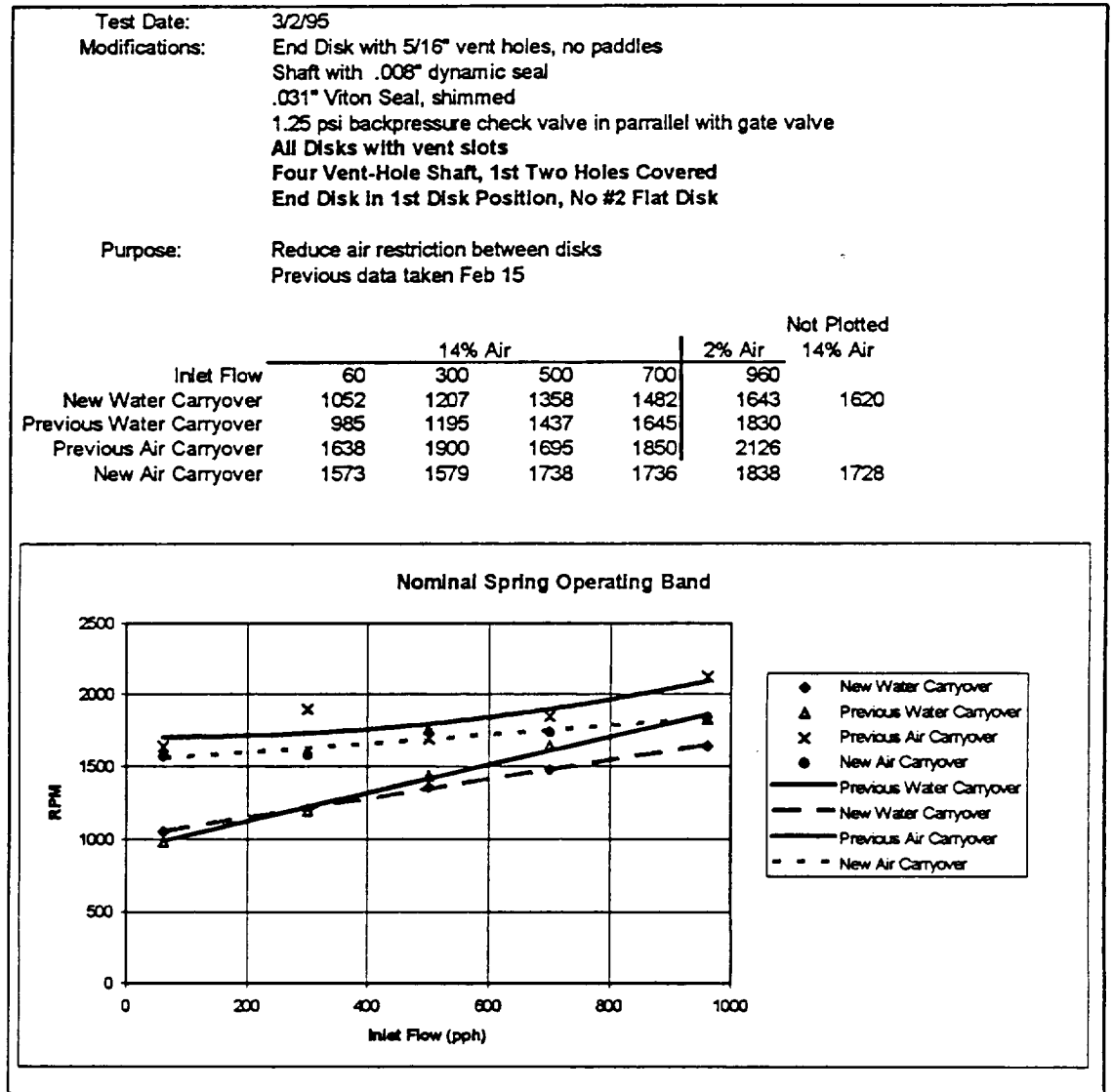


Figure 6-7

CONCLUSIONS REACHED AT THAT TIME:

- Concerns arose that there might be a water restriction in the MLS, especially at higher flow rates, because of the proximity of the first disk to the inlet housing. The use of an End Disk in the first disk position (that nearest the inlet) was a consequence.
- Concerns arose that there might be an air restriction in the MLS. The flat disks were modified to change the vent holes to slots, and the shaft was modified to add two additional vent holes as a consequence.
- The observation that the water ring collapses onto the shaft at the inlet side first led to the use of the new four-vent-hole shaft, but with the first two vent holes covered (those nearest the inlet)

- side). This effectively shifted the shaft's vent hole location two disk "positions" away from the inlet.
- These modifications (i.e.: the inclusion of an End Disk in the first or second disk position, the change to vent slots in the disks, and the shifting of the shaft's vent holes away from the inlet) improved the water carryover performance of the MLS, as evidenced by the lowered RPM values at which water carryover occurs for inlet flows of 500 pph and above.
 - These modifications had a mixed effect on the air carryover curve in that it was now flatter but was also lower in RPM than it had been previously, especially at inlet flows of 500 pph and higher.

6.1.5 TEST PERIOD: Mar 3, 1995 - Mar 12, 1995

SUMMARY:

With the water carryover performance improved, attention focused on air carryover. The apparent lowering of the air carryover curve was not understood. The decision was made to quantify the amount of gas present in the water outlet lines (both process line and main outlet line). As per the MLS Plan of Test, the process line was held at 50 psi downstream of the process pump, after which it returned to ambient pressure. Air carryover measurements were made with the process line at 50 psi and at ambient pressure (labeled 0 psi). In addition, measurements were made at 1900 RPM and at 2500 RPM to help document the effect RPM has on air carryover. The 1900 RPM value is based on the performance mapping using the nominal spring setting (see Figure 6-3 on page 15); it represents the lowest constant RPM value that will avoid water carryover for all inlet flow rates.

As expected, test data indicated that keeping the process line at ambient pressure resulted in higher measurable quantities of air at higher flow rates, as the absence of higher pressure did not force some percentage of the air into solution. All subsequent air carryover measurements were made with the process line at ambient pressure, to provide more accurate measurements and conservative conclusions.

The effect of RPM on air carryover is summarized in Figure 6-8, below. As can be seen, higher RPMs resulted in higher percentages of air present in the water lines, especially at higher flow rates.

Test Date: 3/8/95
Modifications: End Disk with 5/16" vent holes, no paddles
 Shaft with .008" dynamic seal
 .031" Viton Seal, shimmed
 1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
No Backpressure Regulator Present in Process Line

Purpose: Measure Air Carryover in Process and Main Water Outlet Lines vs RPM and Inlet Flow
 Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate

Total Air Carryover with 14% Air in Water at Input		
Inlet Flow (pph)	1900 RPM % Total Air	2500 RPM % Total Air
60		
100	0.020	0.008
300	0.029	0.050
500	0.025	0.038
700	0.039	0.105
960	0.042	0.083

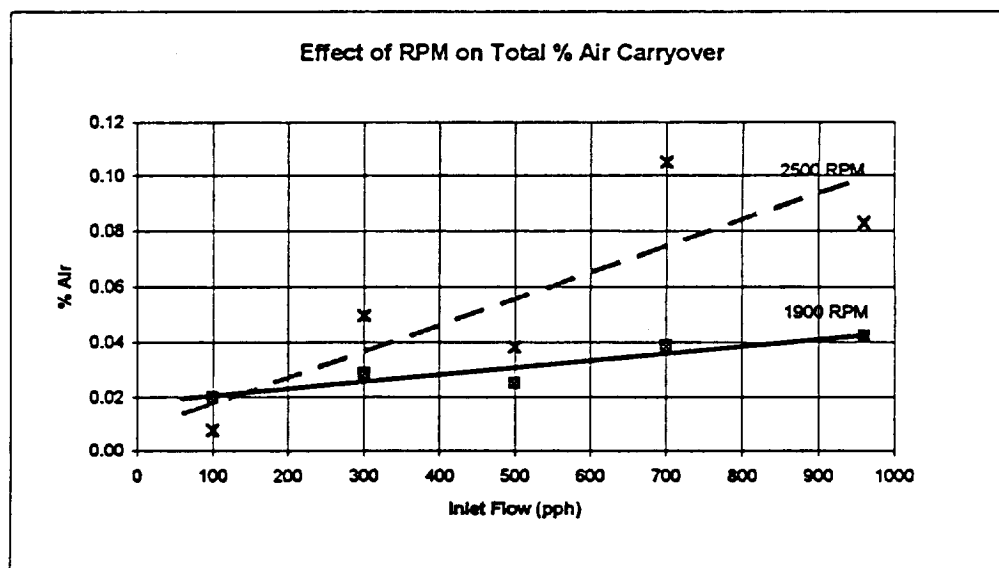


Figure 6-8

The maximum percentage of air allowable in the water carryover had been previously documented to be 0.4%, but this value was based upon the worse value obtained with the pre-development MLS unit mentioned in Section 3. A review by the HSSSI Analysis group established the allowable percentage of

gas carryover that will go back into solution downstream of the 50 psia process pump to be 4.5% air. The measured air carryover was significantly less than this value.

A final observation during this testing was the difficulty in obtaining repeatable data.

CONCLUSIONS REACHED AT THAT TIME:

- The percentage of air that is carried over into the water outlet lines increases with increasing RPM and inlet flow. Because the MLS is designed to be used at a constant RPM, it was concluded that the RPM chosen needs to be as low as practical (i.e.: the lowest value that will avoid water carryover for all flow rates). Based on the performance mapping done with the spring at the Nominal setting, 1900 RPM was chosen as the operating value.
- The air carryover was measurably higher when the process line was not forced to 50 psia, because this high pressure forced some percentage of gas into solution. Because the test setup actually measured free gas, air carryover would henceforth be measured without the 50 psia segment in the process line.
- The worse case total percentage of air present at 1900 RPM was 0.083%, when testing was performed using clean water. Analysis indicated that a maximum of 4.5% gas carryover would go back into solution. The actual air carryover was concluded to be at a reasonable level.
- Obtaining repeatable air carryover data was difficult.

6.2 Soap & Water

With the performance of the MLS mapped and an operating RPM chosen, testing of the MLS was begun using soap and water. Differences in performance were to be documented and compared to those obtained using clean water. It was expected that the performance of the MLS would be affected by the addition of soap to the water - of the three water types that would be used during testing (clean water, soap and water and shower water), the soap and water mixture was expected to result in the highest percentages of air carryover.

Approximately 30 grams of the soap mixture was added to the 8.5 gallons of water in the test setup.

6.2.1 TEST PERIOD: Mar 13, 1995 - Mar 14, 1995, Water Carryover Performance SUMMARY:

The water carryover performance using soap and water was mapped, and is summarized in Figure 6-9. As can be seen, the water carryover curve using soap and water roughly parallels that for clean water, but requires 150 - 350 more RPM. Initial stages of carryover typically consisted of soapy "foam".



Test Date: 3/13-14/1995
Modifications: End Disk with 5/16" vent holes, no pebbles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk

urpose: Map Water Carry-Over in Air Vent Line
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate

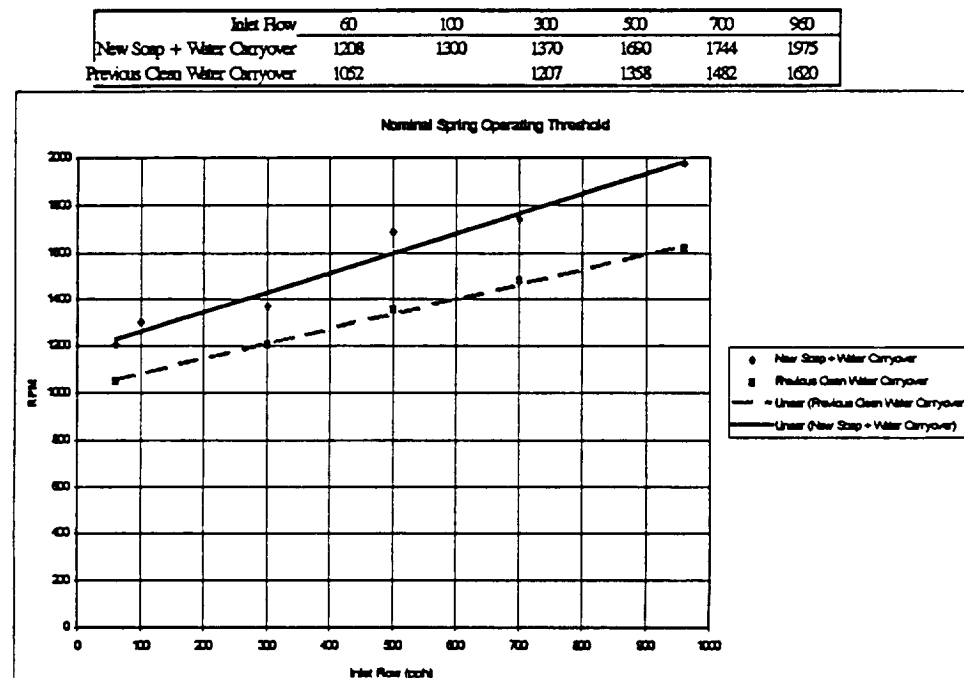


Figure 6-9

CONCLUSIONS REACHED AT THAT TIME:

- The change to soap and water required from 150 - 350 more RPM to prevent water carryover. The water carryover curve obtained roughly paralleled that made using clean water.

6.2.2 TEST PERIOD: Mar 14, 1995 - Mar 28, 1995, Air Carryover Performance SUMMARY:

Began to map the air carryover performance using soap and water. Repeatability of data and higher than anticipated air carryover results (with total percent air carried as high as 0.9%)

became the main areas of concern. Venting of air was still occurring either continuously or at discrete times. It was then observed that the control piston did not appear to be responding to the pressure changes acting upon it during venting. It was concluded that this situation could account for the performance seen. Upon disassembly of the MLS, it was found that the nut which tightens the control piston down onto the control assembly had loosened, thereby allowing the piston to wobble considerably. In operation, this would allow the pressures that normally act upon the piston to equalize with each other, bypassing the piston. The nut was tightened, and the air carryover performance again mapped. A "hump" appeared in the air carryover curve, in that the air carryover was elevated in the 150 - 600 pph inlet flow range when compared with the other values obtained. See Figure 6-10.

Test Date: 3/20-28/1995
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi

Purpose: Map Combined % Air Carry-Over
Data taken with unit in both horizontal and vertical (inlet down) positions
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, 1900 RPM

Summary: "Bump" in curve for unit in horizontal position attributed to 1g effects on 200-600 pph inlet flow in pre-swirl cham.
1g effects eliminated by turning unit to vertical.
Re-check of horizontal results eight days later confirms that improvement seen in vertical position
is not attributable to "aging" soap and water sample

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring				
Inlet Flow (pph)	Clean Water % Total Air	3/20/95 Horizontal Soap + Water % Total Air	3/23-27/95 Vertical Soap + Water % Total Air	3/28/95 2nd Horizontal Soap + Water % Total Air
60		0.105	0.055	
100	0.020	0.064		
200		0.238	0.084	
300	0.029	0.590	0.068	0.485
500	0.025	0.451	0.063	0.384
600		0.160	0.033	
700	0.039	0.099	0.041	0.094
960	0.042	0.052	0.043	

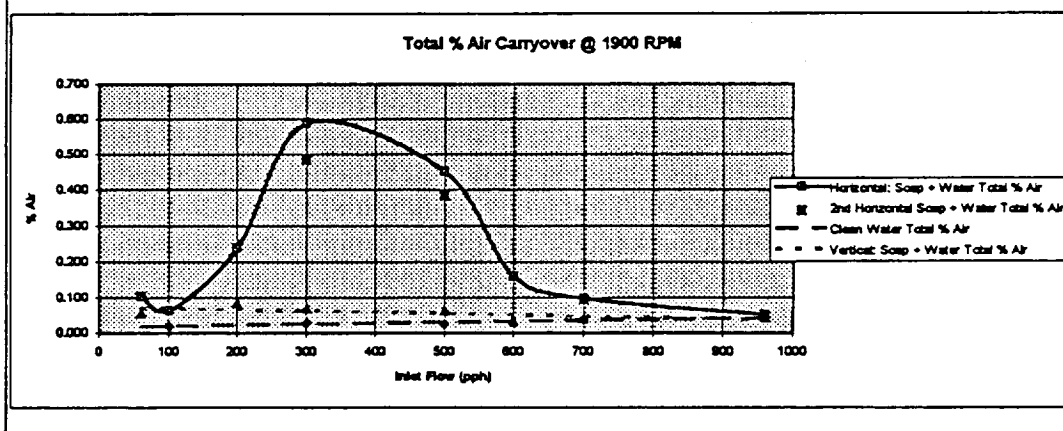


Figure 6-10

Discussions concerning this data led to the conclusion that it was a side-effect of the pre-swirl chamber. It was believed, and visual observation through the plastic MLS tended to support, that at low flows (60-100 pph), the water stream merely trickled into the pre-swirl chamber due to its low inlet velocity. At the high flows (700 -960 pph), the inlet flow swirled entirely around the perimeter of the pre-swirl chamber due to its high inlet velocity. However, at the intermediate flow ranges, the inlet flow began to travel along the wall of the chamber, but then collapsed due to gravity, falling to the bottom and causing additional aeration of the soap and water solution. As this problem (high air carryover) was not encountered using clean water, it was concluded that the addition of soap was the enabling factor in causing elevated air carryover. Since a

redesign of the pre-swirl chamber was impractical within the context of the current program, it was decided that the situation could be remedied by designing a disk that would extend into the pre-swirl chamber from the first disk position. This new disk would help force the inlet stream into a rotational flow. A new Inlet Disk, SVSK121960-1, was designed to meet these requirements.

Because the problem with the pre-swirl chamber was essentially a 1g effect, it would not be expected to occur in space, nor would it be expected to occur if the MLS were oriented vertically. To verify this, the MLS was reoriented vertically with the inlet down. The air carryover performance was again mapped. Referring to Figure 6-10, it can be seen that the "hump" disappears, that the air carryover curve is linear, and that it is slightly higher than it was with clean water. It was therefore concluded that the "hump" seen was indeed a 1g inlet housing phenomenon.

The possibility existed that the improvement seen in the air carryover was attributable to the age of the soap and water solution (the soap and water solution had been in use for two weeks at this point). To verify, the MLS was repositioned in a horizontal orientation and some data points were obtained. Referring to the points labeled "2nd Horizontal Soap & Water..." in Figure 6-10, it can be seen that the "hump" in the air carryover curve reappears. It was concluded that the improvement in air carryover seen in the vertical orientation was not attributable to an aging effect of the water.

As has been mentioned previously, it was observed during this portion of testing that the venting of air would still occur either continuously or discretely, although the discrete mode was observed as being the predominant one. The ability to obtain repeatable air carryover data was at times difficult and a connection between the discrete venting and elevated air carryover seemed to exist. These were areas of concern, but since the overall results were favorable, it was decided to proceed on to testing with shower water to further assess the effects of different waters on performance.

CONCLUSIONS REACHED AT THAT TIME:

- The effectiveness of the pre-swirl chamber was affected by gravity (a 1g phenomenon).
- The water and vertical air carryover curves were considered acceptable, and no change to the 1900 RPM operating speed of the MLS was considered necessary.
- A new inlet disk (SVSK121960-1) was designed to correct the 1g phenomenon. It would extend into the pre-swirl chamber and force the inlet stream into rotational flow.
- Air venting of the MLS would occur either continuously, or more commonly, at discrete intervals.

6.3 Shower Water

With the performance of the MLS mapped using soap and water, testing began using collected shower water, as per the MLS Plan of Test. Until such time that the new SVSK121960-1 Inlet Disk would become available, air carryover performance was made with the MLS in both the horizontal and inlet-down vertical positions.

6.3.1 TEST PERIOD: Mar 29, 1995 - Apr 10, 1995, Air Carryover Performance

SUMMARY:

Began mapping the air carryover performance in the horizontal orientation. Data suggested that performance was worse than it had been using soap and water. The "hump" reappeared as expected, but a total air carryover of 1.440% was recorded at 200 pph inlet flow. When the unit was turned to the vertical (inlet down) orientation, a problem was found with the shaft seal; it was leaking water onto the motor and consequently affecting the RPM control. The motor was removed and cleaned, and testing resumed. Observations indicated that the RPM would still fluctuate with the MLS oriented vertically. It was apparent that the RPM fluctuations were directly influenced by the discrete venting cycle.

Since the motor had been repaired, it was decided to re-map the MLS air carryover performance in the horizontal orientation. The performance was improved. Figure 6-11 shows these results along with the results obtained with clean water and soap and water for comparison. As expected, the magnitude of air carryover was less using shower water than it was using soap and water. A slight "hump" was apparent in the air carryover curve, as was seen with soap and water.



Test Date: 4/4/95 - 4/5/95
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi

Purpose: Map Combined % Air Carry-Over. Summarize for clean water, soap & water, shower water
Data taken with unit in horizontal orientation
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, 1900 RPM, Nominal Spring Setting

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring			
Inlet Flow (gph)	Clean Water % Total Air	Horizontal Soap + Water % Total Air	4/5/95 Horizontal Shower Water % Total Air
60		0.105	0.116
100	0.020	0.064	0.023
200		0.238	0.172
300	0.029	0.590	0.112
500	0.025	0.451	0.080
600		0.160	0.018
700	0.039	0.099	0.010
950	0.042	0.052	0.021

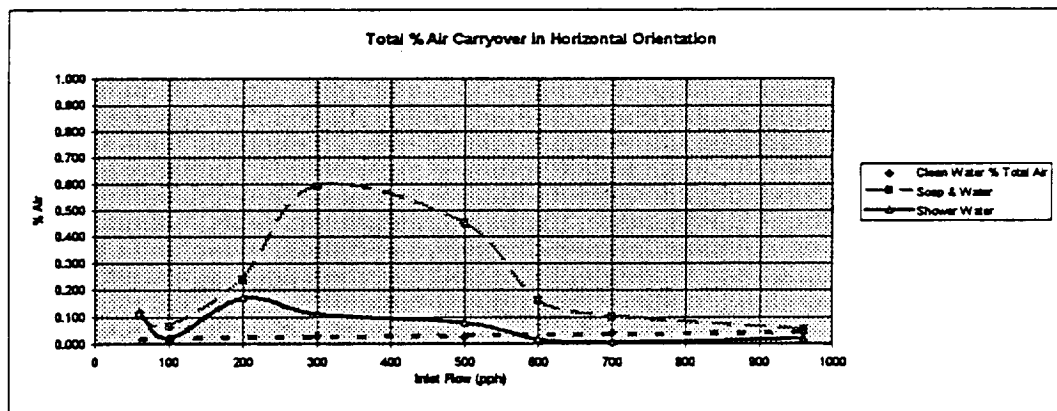


Figure 6-11

Re-mapped the vertical orientation air carryover (inlet down) performance. Repeatability of data was again difficult to achieve, and as before the focus was on trying to maintain as constant a backpressure as possible. The idea emerged that the backpressure check valve was sticking. Impacting the valve sometimes seemed to "correct" this problem. Later observations noted the presence of severe turbulence within the MLS downstream (from the point of view of the water rotation) of the main water exit port. Rapid intentional cycling of the solenoid valve seemed to "correct" this problem. Acceptable data was eventually obtained, and is shown in Figure 6-12 along with similar data for clean water and soap and water. The shower water curve is nearly identical to the clean water horizontal performance curve.

Test Date: 4/6/94 - 4/10/1995

Modifications: End Disk with 5/16" vent holes, no paddles
 Shaft with .008" dynamic seal
 .031" Viton Seal, shimmed
 1.25 psi backpressure check valve in parallel with gate valve
 All Disks with vent slots
 Four Vent-Hole Shaft, 1st Two Holes Covered
 End Disk in 1st Disk Position, No #2 Flat Disk
 Process Line at 0 psi

Purpose: Map Combined % Air Carry-Over. Summarize for clean water, soap & water, shower water
 Data taken with unit in Vertical orientation
 Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, 1900 RPM, Nominal Spring Setting

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring			
Inlet Flow (gph)	Horizontal Clean Water % Total Air	Vertical (Inlet Down) Soap + Water % Total Air	Vertical (Inlet Down) Shower Water % Total Air
80		0.055	0.022
100	0.020		0.007
200		0.084	0.040
300	0.029	0.058	0.053
500	0.025	0.053	0.014
600		0.033	0.000
700	0.039	0.041	0.029
950	0.042	0.043	0.049

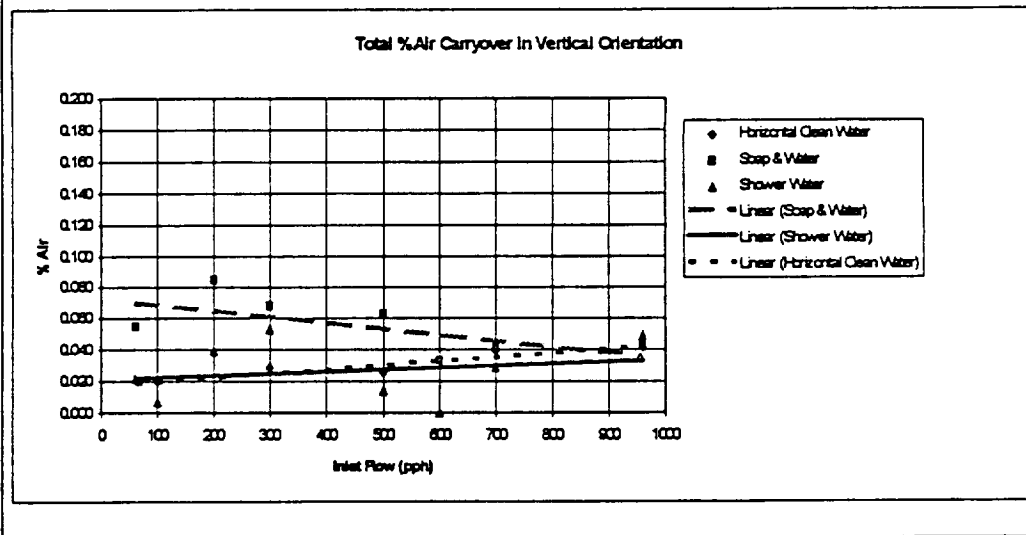


Figure 6-12

CONCLUSIONS REACHED AT THAT TIME:

- The horizontal orientation air carryover performance using shower water was similar to that obtained using soap and water in that a “hump” appeared in 200 - 500 pph inlet flow range. The overall magnitude of air carryover was less than it was with soap and water.
- The vertical orientation air carryover performance using shower water was similar to that using clean water in a horizontal orientation. Repeatability and point-to-point variation of data continued to be areas of concern. Focus was again on trying to maintain as constant backpressure as possible, as it was believed that doing so would improve performance and repeatability.
- Maintaining a constant backpressure was anticipated to result in improved performance.
- Variations in RPM occurred when the MLS was oriented vertically, and were directly influenced by the discrete venting cycle.

**6.3.2 TEST PERIOD: Apr 12, 1995 - Apr 13, 1995, Water Carryover Performance
SUMMARY:**

The water carryover performance using shower water was mapped, and is summarized in Figure 6-13. As can be seen, the water carryover curve using shower water is nearly identical to that clean water.



Test Date: 4/12 - 13/1995
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi

Purpose: Map Water Carry-Over in Air Vent Line
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting
Data taken with unit in horizontal orientation

	RPM at Which Water Carryover Occurs					
	Nominal Spring, 14% Air at Inlet					
Inlet Flow	60	100	300	500	700	900
Shower Water	1193	1195	1340	1418	1549	1684
Soap + Water	1208	1300	1370	1690	1744	1975
Clean Water	1052		1207	1358	1482	1620

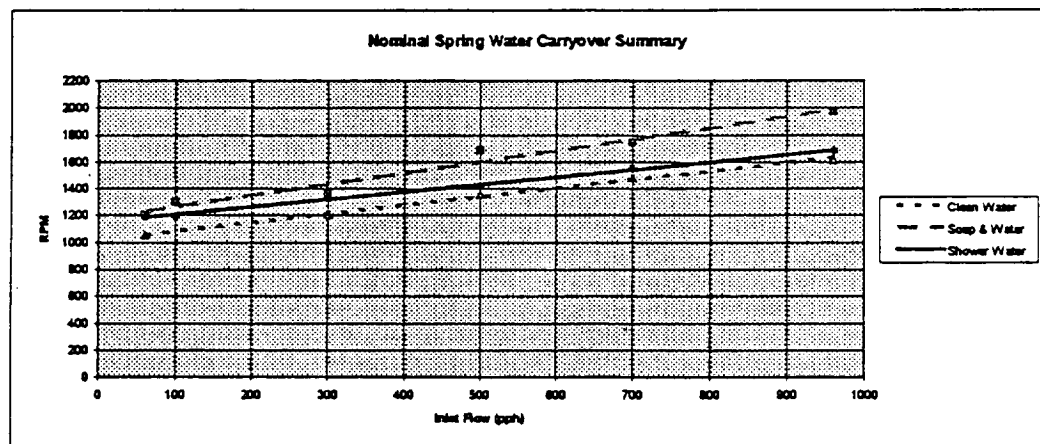


Figure 6-13

CONCLUSIONS REACHED AT THAT TIME:

- The change to shower water from clean water required from 60 - 150 additional RPM to prevent water carryover
- The water and air carryover performance obtained using shower water required no change to the previously selected 1900 RPM operating speed.

6.3.3 TEST PERIOD: Apr 17, 1995 - Apr 28, 1995, Testing Using P/N SVSK121960-1 Inlet Disk

SUMMARY:

The newly designed SVSK121960-1 Inlet Disk was evaluated. This disk was designed to correct the lg effect seen in horizontal orientation air carryover using soap and water and shower water.



The new inlet disk was installed in the first disk position (closest to the inlet), and the 2nd flat disk was reinstalled (which had not been present when the End Disk was installed in the first position, due to interference).

To verify the performance improvement expected, soap and water was used, as the highest amounts of air carryover were demonstrated to occur with this water type. The water and air carryover performance in both the horizontal and vertical orientations was mapped, and the results are summarized in Figure 6-14 and Figure 6-15.

Test Date: 4/20/95
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .003" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
New PIN SVSK121960-1 Inlet Disk, Flat Disk in No 2 Position
Process Line at 0 psi

Purpose: Verify New Inlet Disk Improves Performance
Map Water Carry-Over in Air Vent Line using Soap & Water
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting
Data taken with unit in horizontal orientation

Reference: Prior Configuration Data Taken 3/13-14/95

Effect of New Inlet Disk RPM at Which Water Carryover Occurs Nominal Spring, 14% Air at Inlet, Soap & Water							
Inlet Flow	60	100	200	300	500	700	950
New Inlet Disk	1193		1409		1770	1899	1921
Prior Configuration	1208	1300	1370	1690	1744	1975	

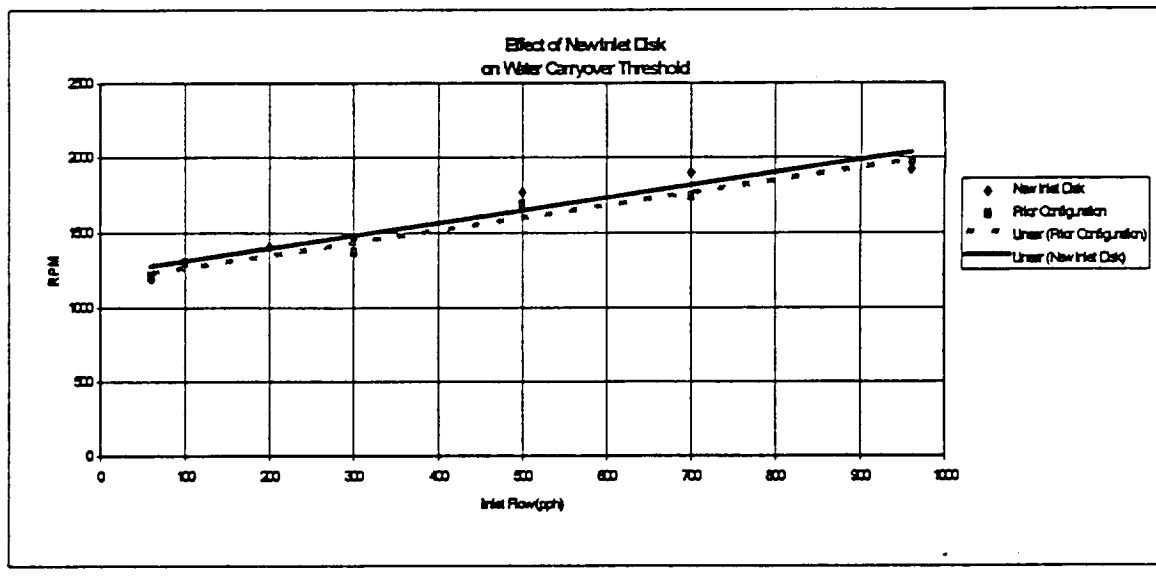


Figure 6-14



Test Date: 4/21-27/1995
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
New P/N SVSK121960-1 Inlet Disk, Flat Disk In No 2 Position
Process Line at 0 psi

Purpose: Verify New Inlet Disk Improves Performance:
Map Combined Air Carryover in Water Lines using Soap & Water, Horizontal & Vertical Positions
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Prior Configuration Horizontal Data Taken 3/20-28/95
Prior Configuration Vertical Data Taken 3/23-27/95

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring				
Inlet Flow (gph)	Previous Horizontal Soap + Water % Total Air	New Inlet Disk Horizontal Soap + Water % Total Air	New Inlet Disk Vertical Soap + Water % Total Air	Previous Vertical Soap + Water % Total Air
	% Total Air	% Total Air	% Total Air	% Total Air
60	0.105	0.090	0.100	0.055
100	0.064	0.347	0.202	
200	0.238	0.521	0.170	0.087
300	0.590	0.413	0.164	0.068
500	0.451	0.161	0.031	0.063
600	0.160	0.149	0.075	0.033
700	0.099	0.104	0.010	0.041
800		0.077	0.031	
960	0.052	0.046		0.043

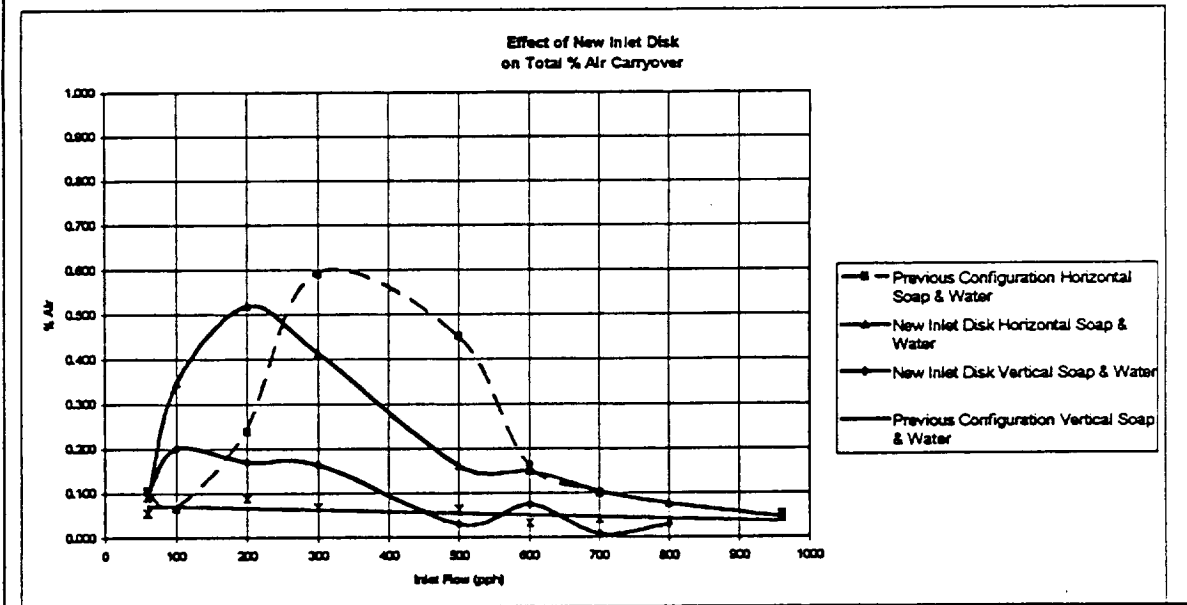


Figure 6-15



The addition of the new inlet disk was judged to have no effect on water carryover performance. As can be seen in Figure 6-15, the new inlet disk did not eliminate the "hump" in the horizontal orientation air carryover curve, which was not expected. Furthermore, it appeared as if the "hump" in the curve shifted towards the lower RPMs, with the maximum carryover now occurring at 200 pph inlet flow versus the previous maximum at ~ 350 pph. When oriented in the vertical orientation, the air carryover performance did not approach the performance of the previous configuration; elevated percentages of air carryover were evident in the 100 - 300 pph inlet flow range were present. Obtaining good air carryover measurements (in both orientations) was again difficult, as has been previously discussed.

The solenoid valve failed to a closed position while measuring air carryover at the last data point (960 pph), and consequently no value is plotted.

CONCLUSIONS REACHED AT THAT TIME:

- The addition of the new P/N SVSK121960-1 Inlet Disk did not affect the water carryover performance of the MLS when tested using soap and water.
- The new P/N SVSK121960-1 Inlet Disk did not eliminate the "hump" in the horizontal air carryover performance map.

6.4 Extended Performance Testing

As originally defined in the MLS Plan of Test, an Extended Performance Test would be conducted on a second MLS unit as the last part of testing under this program. The primary purpose of this test would be to gather experience on how the MLS works in near-continuous longer-term operation using "real" water.

All parties agreed that it would be advantageous to begin the Extended Performance Testing as soon as was practical - it was agreed that a second rig would be set-up to allow further developmental testing to occur in parallel with the Extended Performance Testing. It was further agreed that shower water would be used to conduct this testing.

To better reflect these ideas on how the Extended Performance Test should proceed, a supplementary MLS Extended Performance Test Plan was developed (see Appendix III: MLS Extended Performance Test Plan on page 74). The primary objective of this test would be to document the effect extended duration operation using shower water has on the reliability and operation of the MLS. To help quantify any changes, the metal MLS unit was to be performance mapped before and after the extended performance portion of the test.

As described, a second metal MLS unit was manufactured and assembled for testing. A summary of this phase of testing follows:

6.4.1 TEST PERIOD: May 1, 1995 - May 9, 1995, Metal MLS Clean Water Performance

SUMMARY:

The Metal MLS was fitted with a disk assembly that did not use the new P/N SVSK121960-1 Inlet Disk. The first disk position was occupied by an End Disk, as was previously done with the plastic unit. The control piston assembly (including the diaphragm seal and its shims) from the plastic MLS was also used. Measurements indicated that no change to the seal shims were required. Several attempts were made to assemble both the inlet housing and main housing

together - most attempts resulted in broken bearings and damaged seals. Rather than delay the initiation of the Extended Performance Test any further, it was decided that it would be acceptable to use the plastic inlet housing with the metal main housing, as these parts easily mated.

Once assembled, the water and air carryover performance were mapped using clean water. As can be seen in Figure 6-16, the water carryover performance between the plastic and metal MLS units is nearly identical. An observation during this period of testing was that slight amounts of water would "spit" out of the air vent line whenever the RPM was lowered. This was attributed to problem with the plastic washer seal at the end of the shaft, and was not considered serious. The use of the plastic washer was only meant as an expedient fix to the water leakage problem discussed in Section 6.1.3.

Test Date: 5/5-8/1995
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi
Metal Main Housing/Plastic Inlet Housing

Purpose: Verify Metal Unit's Performance By Comparing To Plastic Unit
Map Water and Combined Air Carryover Using Clean Water
Constant Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1500 RPM

Reference: Plastic Unit Water Carryover Data Taken March 2

Inlet Flow	60	100	300	500	700	900
New Metal Unit Water Carryover	1130	1150	1301	1384	1423	1677
Previous Plastic Unit Water Carryover	1052		1207	1358	1482	1620

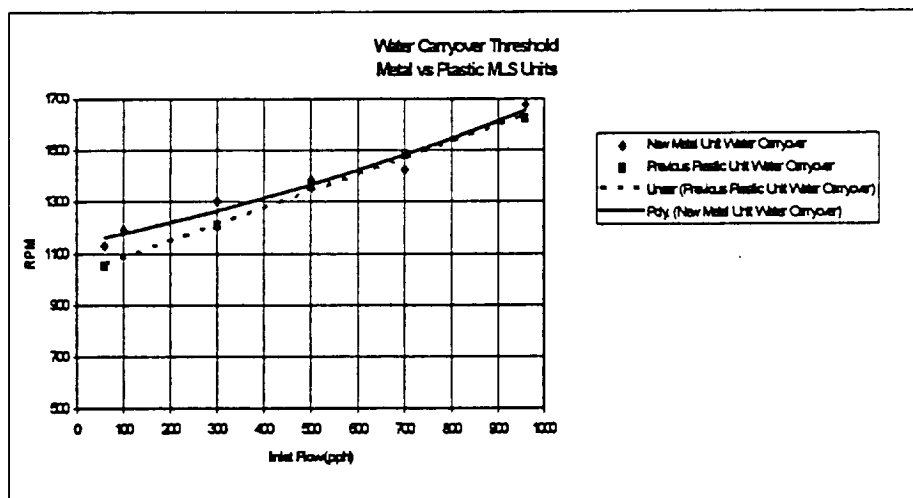


Figure 6-16

The horizontal orientation air carryover performance using clean water was mapped, and the results are shown in Figure 6-17. Note that the Metal unit's air carryover performance is markedly improved versus the plastic unit's. No air carryover was frequently recorded. Observation during these tests noted that virtually no bubbles were seen in the water outlet lines. Recall that it was the observation of such bubbles in the process line when testing the plastic unit that led to the premature conclusion that the air carryover seen was unacceptable. No explanation could be provided for this change, although it does suggest that the MLS has the ability to remove nearly all free gas from the inlet water stream under similar conditions.

Test Date: 5/8-8/95
Modifications: End Disk with 5/16" vent holes, no paddles
 Shaft with .003" dynamic seal
 .031" Viton Seal, shimmed
 1.25 psi backpressure check valve in parallel with gate valve
 All Disks with vent slots
 Four Vent-Hole Shaft, 1st Two Holes Covered
 End Disk in 1st Disk Position, No #2 Flat Disk
 Process Line at 0 psi
 Metal Main Housing/Plastic Inlet Housing

Purpose: Verify Metal Unit's Performance By Comparing To Plastic Unit
 Map Water and Combined Air Carryover Using Clean Water
 Constant Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Plastic Unit Horizontal Data Taken March 8

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring		
Inlet Flow (gph)	Plastic Unit Horizontal Clean Water % Total Air	Metal Unit Horizontal Clean Water % Total Air
60		0.002
100	0.020	0.001
300	0.029	0.000
500	0.025	0.000
700	0.039	0.000
960	0.042	0.000

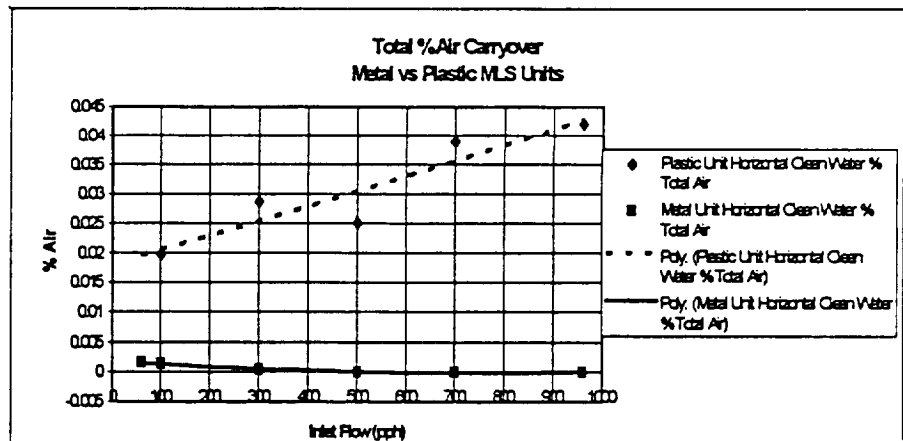


Figure 6-17



CONCLUSIONS REACHED AT THAT TIME:

- When tested using clean water, the metal MLS unit was identical to the plastic one in terms of water carryover performance, and was superior in terms of horizontal air carryover performance.
- No measurable air was present in the water outlet lines for several data points. It was not known why the air carryover performance was so improved, although these results suggest that the MLS has the ability to remove nearly all free gas from the inlet water stream under similar conditions.

6.4.2 TEST PERIOD: May 12, 1995 - May 14, 1995, Backpressure Valve

SUMMARY:

A new Backpressure Valve Assembly, P/N SVSK121970-1, had been designed to better regulate the backpressure. Its intended purpose was to maintain a constant backpressure regardless of the inlet flow rate, thus eliminating the need to use the check valve in parallel with the gate valve. Better regulation of backpressure was expected to result in improved air carryover performance. The new valve was designed with the ability to vary the height of a spring, thereby allowing the desired amount of backpressure to be set.

The new backpressure valve was installed in place of the previously used valves, and calibration runs were made with 60 pph inlet flow and various spring height settings. Using the lowest spring setting obtainable, the backpressure was 1.125 psi. When the inlet flow was increased to 700 pph, the backpressure increased to 2.6 psi.

A complete map of backpressure versus inlet flow was then made at this spring setting, and the results clearly showed that the backpressure was a function of the inlet flow - an undesirable result. To document how the valve body without its pressure regulating components responded to the inlet flow, the P/N SVSK121973-1 Valve Poppet was removed from the backpressure assembly, and a similar backpressure versus inlet flow map made. The results clearly showed that the valve body itself was contributing to the backpressure, and implied that the diameter of the outlet line needed to be increased. These results are summarized in Figure 6-18.

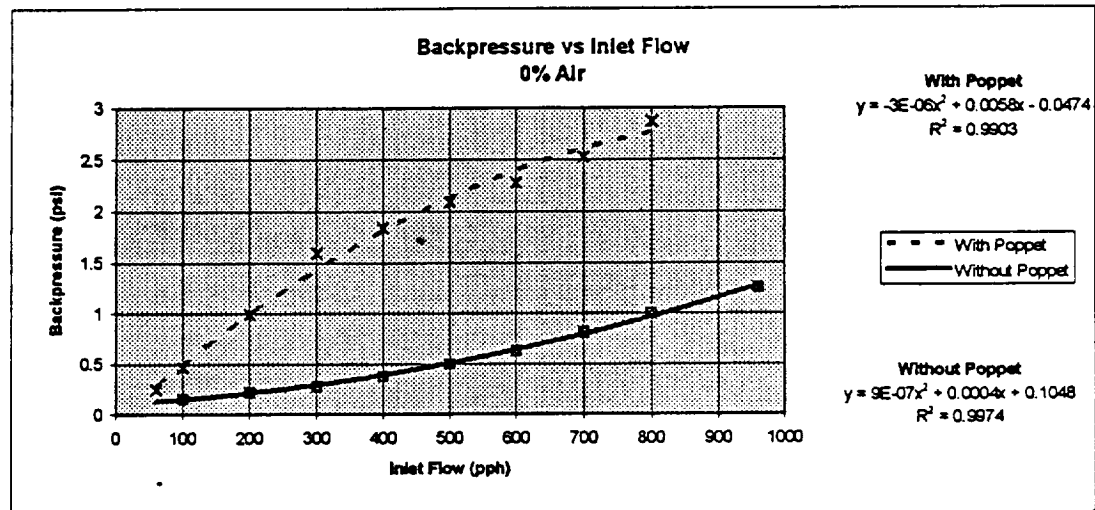


Figure 6-18

CONCLUSIONS REACHED AT THAT TIME:

- The new backpressure valve did not provide a constant backpressure that was independent of inlet flow.
- The diameter of the main water outlet line may need to be increased.

6.4.3 TEST PERIOD: May 15, 1995 - May 17, 1995, Metal MLS Water Carryover Performance in Shower Water

SUMMARY:

The new Backpressure Regulating Assembly was removed and the previously used gate valve in parallel with the check valve assembly was reinstalled.

The test rig was filled with shower water to map the performance of the metal MLS unit prior to the Extended Performance portion of the test. A similar map would be made at the conclusion of that test, and a comparison between the two would help to document any performance changes.

Water carryover performance was mapped, and the results are shown in Figure 6-19. As can be seen, water carryover performance was essentially unchanged.

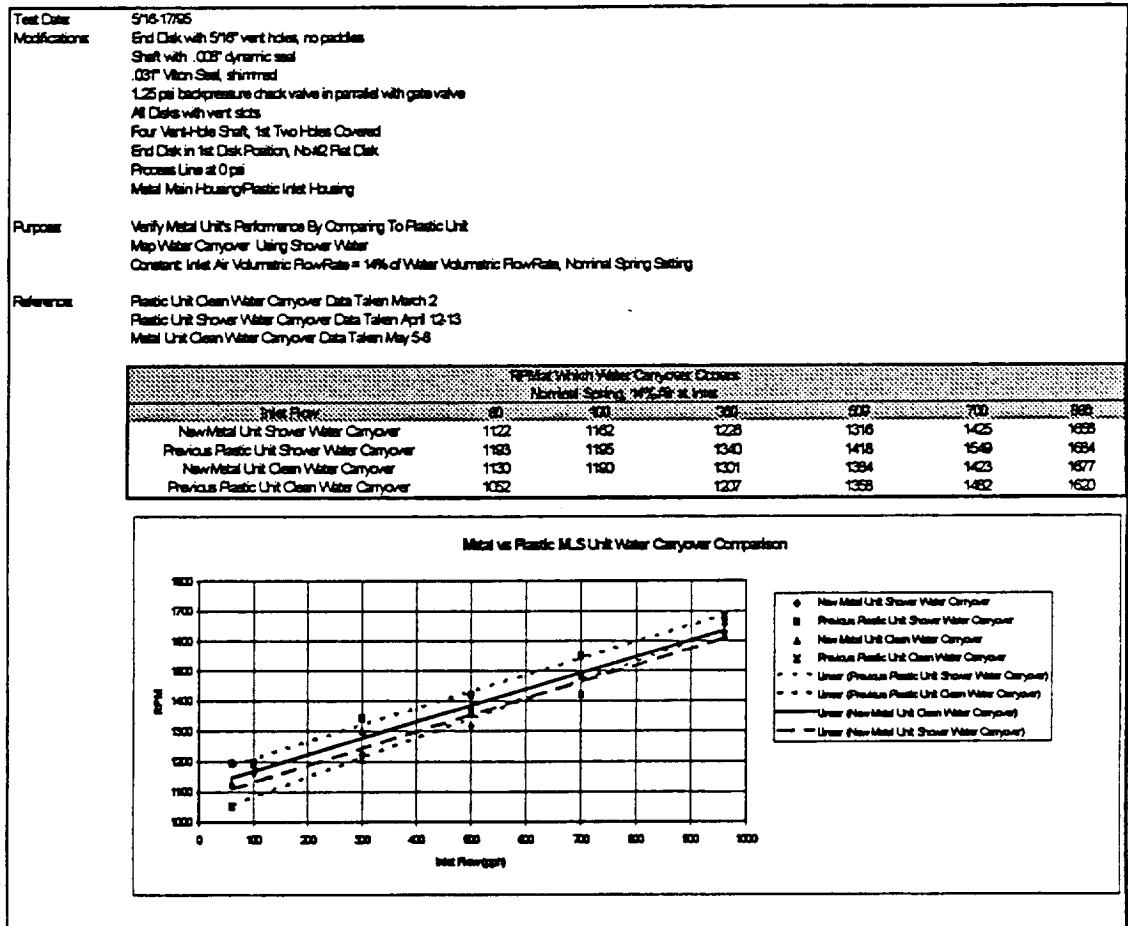


Figure 6-19

CONCLUSIONS REACHED AT THAT TIME:

- Water carryover performance of the metal MLS unit using either clean water or shower water was essentially unchanged from the results obtained using the plastic MLS unit with similar waters.

6.4.4 TEST PERIOD: May 18, 1995 - June 6, 1995, Metal MLS Air Carryover Performance in Shower Water

SUMMARY:

Mapping of the air carryover performance in the horizontal orientation indicated excessive air carryover. An observation was that the gas venting was exclusively occurring in discrete intervals during this portion of testing (with the side effect of having the backpressure momentarily drop to nearly 0 psi at each venting cycle) - again indicating that unstable backpressure and poor air carryover performance are related.

When testing began with the unit in the vertical (inlet down) orientation, the operation of the MLS became very difficult in that the MLS would frequently get into an operating mode in which the air carryover performance was significantly impacted. Repeated attempts were frequently necessary to get and keep the unit into a "stable" operating environment.

It was decided to remove the check valve and replace it with the new SVSK121970-1 Backpressure Valve Assembly. It was hoped that this new valve, when used in parallel with the gate valve to regulate backpressure, would better regulate the backpressure. Figure 6-20 shows this new setup schematically.

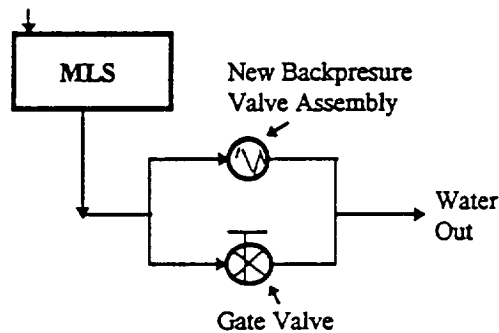


Figure 6-20: New Backpressure Valve in Parallel with Gate Valve

After installation, test results and observations indicated that venting still occurred in discrete intervals, with no discernible difference in air carryover noted. This result was observed with the gate valve open or totally closed. Horizontal air carryover performance was as high as 1.4%. These results are seen in Figure 6-21.

Test Date: 5/18-22/95
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi
Metal Main Housing/Plastic Inlet Housing

Purpose: Verify Metal Unit's Performance By Comparing To Plastic Unit
Map Combined Air Carryover Using Shower Water
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Plastic Unit Horizontal Orientation Shower Water Data Taken April 5

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring			
Inlet Flow (pph)	Plastic Unit Horizontal Shower Water % Total Air	Metal Unit Horizontal Shower Water % Total Air	Metal Unit Vertical Shower Water % Total Air
60	0.116	0.154	0.020
100	0.023	1.455	0.625
200	0.172	1.184	0.332
300	0.112	0.714	0.247
500	0.080	0.407	0.174
600	0.018	0.316	0.049
700	0.010	0.057	0.086
950	0.021	0.029	0.050

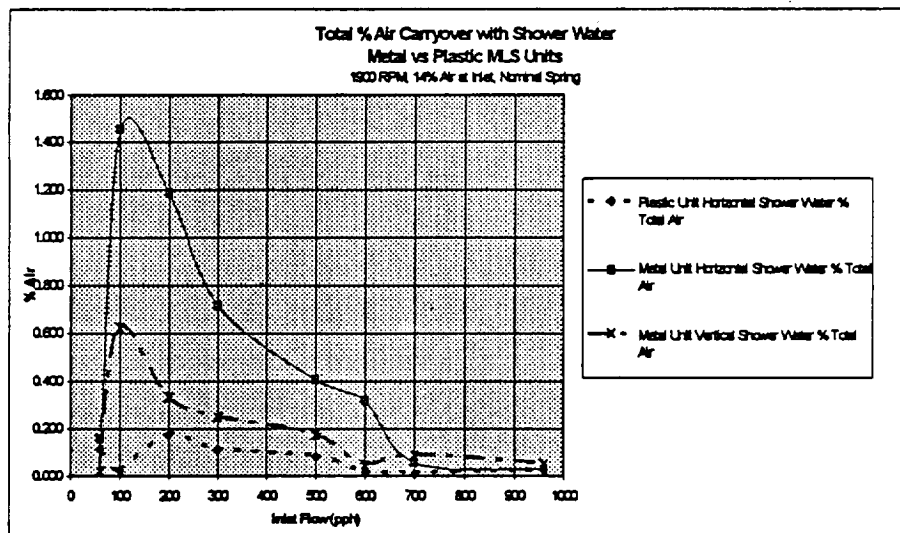


Figure 6-21

Discussions concerning these results were held. To reiterate, the general observation was that the air primarily vented at discrete times, rather than continuously. The backpressure would momentarily go to 0 psi when venting occurred, and the depth of the water ring would increase

as the gas was vented. The RPM would consequently change in response to the changing depth of the water ring. It was felt that the interaction of each of these responses resulted in the relative instability seen in the operation of the MLS unit, and that this instability affected air carryover performance. Several suggestions emerged. The first centered on the fact that the motor RPM was affected by the changing water ring depths caused by the discrete venting cycle. The varying RPM would affect the pressures acting upon the control piston, which in turn controlled the venting process. In actual application, the motor speed would be constant. It would therefore be desirable to use a synchronous motor during testing that would be able to hold a constant RPM regardless of the load applied; budgetary and time constraints prevented any further action on this program.

A second suggestion arose over the shape of the air carryover curves. Referring to Figure 6-21, it can be seen that the highest amounts of air carryover occurred with 100 pph inlet flow, but were at or near their lowest values at 60 pph. This was true for both the horizontal and vertical orientations. Suspicions were raised over this observation, because a different pump was used to produce the 60 pph flow than for the others. Water flow rates were regulated by two bypass valves, one placed before the pump and one after. The idea emerged that too much bypass was being used to establish a low flow condition (i.e. 100 pph) with a pump sized to produce up to 960 pph, and that the pump might be cavitating. It was decided to regulate flow by using variable pump speed instead of bypass and see if that change made an improvement. A variable AC transformer (VariAC) was then attached to the pump power line, and the bypass valves were closed.

A third suggestion was that something had changed within the metal MLS to cause its poor shower water performance, and that it should be disassembled and inspected.

Testing resumed to address the second suggestion. Using a VariAC to regulate flow and the new backpressure relief valve in parallel with a gate valve to regulate backpressure, some performance points were taken in both the horizontal and vertical orientations. The majority, though not all, of these points showed improved air carryover. To further assess the performance of the metal unit, a performance graph was made showing the best values yet obtained for each inlet flow, and is shown in Figure 6-22.



Test Date: 5/18-24/95
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi
Metal Main Housing/Plastic Inlet Housing
New Backpressure Relief Valve in parallel with gate valve
Inlet Flow Regulated By Pump Speed (No Bypass)

Purpose: Verify Metal Unit's Performance By Comparing To Plastic Unit
Map Combined Air Carryover Using Shower Water
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Plastic Unit Horizontal Orientation Shower Water Data Taken April 5
Plastic Unit Vertical Orientation Shower Water Data Taken April 6-10

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring				
Inlet Flow (pph)	Plastic Unit Horizontal Shower Water % Total Air	Metal Unit Horizontal Shower Water % Total Air	Plastic Unit Vertical (Inlet Down) Shower Water % Total Air	Metal Unit Vertical (Inlet Down) Shower Water % Total Air
60	0.116	0.154	0.022	0.020
100	0.023	0.847	0.007	0.341
200	0.172	0.901	0.040	0.301
300	0.112	0.714	0.053	0.159
500	0.080	0.333	0.014	0.174
600	0.018	0.316	0.000	0.049
700	0.010	0.057	0.029	0.086
960	0.021	0.029	0.049	0.050

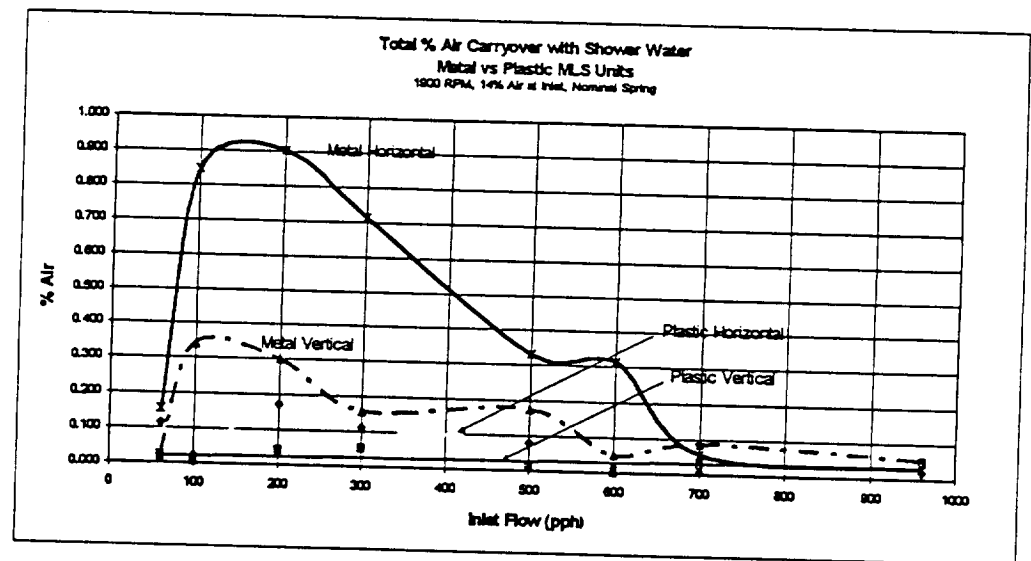


Figure 6-22

It was not understood why the horizontal air carryover performance for the metal unit was so different than it was for the plastic unit, or even why it was so different from that obtained using clean water. The test rig was emptied and filled with clean water to repeat the horizontal air

carryover map. The results (labeled 5/25/95 on the chart below) did not resemble the original ones. It was concluded that something within the MLS had changed.

The metal MLS was disassembled and inspected, and the only discrepancies noted was that one of the plastic rings used to shim the OD of the diaphragm seal had been damaged, that the SVSK120993-1 spring adjuster was not completely seated in the MLS housing because it was too tight a fit, and that the SVSK120985-1 Antirotaion pin (item # 50 on the MLS assembly drawing) needed minor straightening. The spring adjuster was removed and replaced with the one used in the plastic MLS, the damaged shim replaced and the pin straightened. The metal MLS unit was reassembled, and another clean water air carryover performance map made (labeled 5/30/95 on the chart below). Although it did not totally duplicate the original, it was markedly improved (and less than the values obtained with the plastic unit) and concluded to be acceptable. These results are summarized in Figure 6-23.

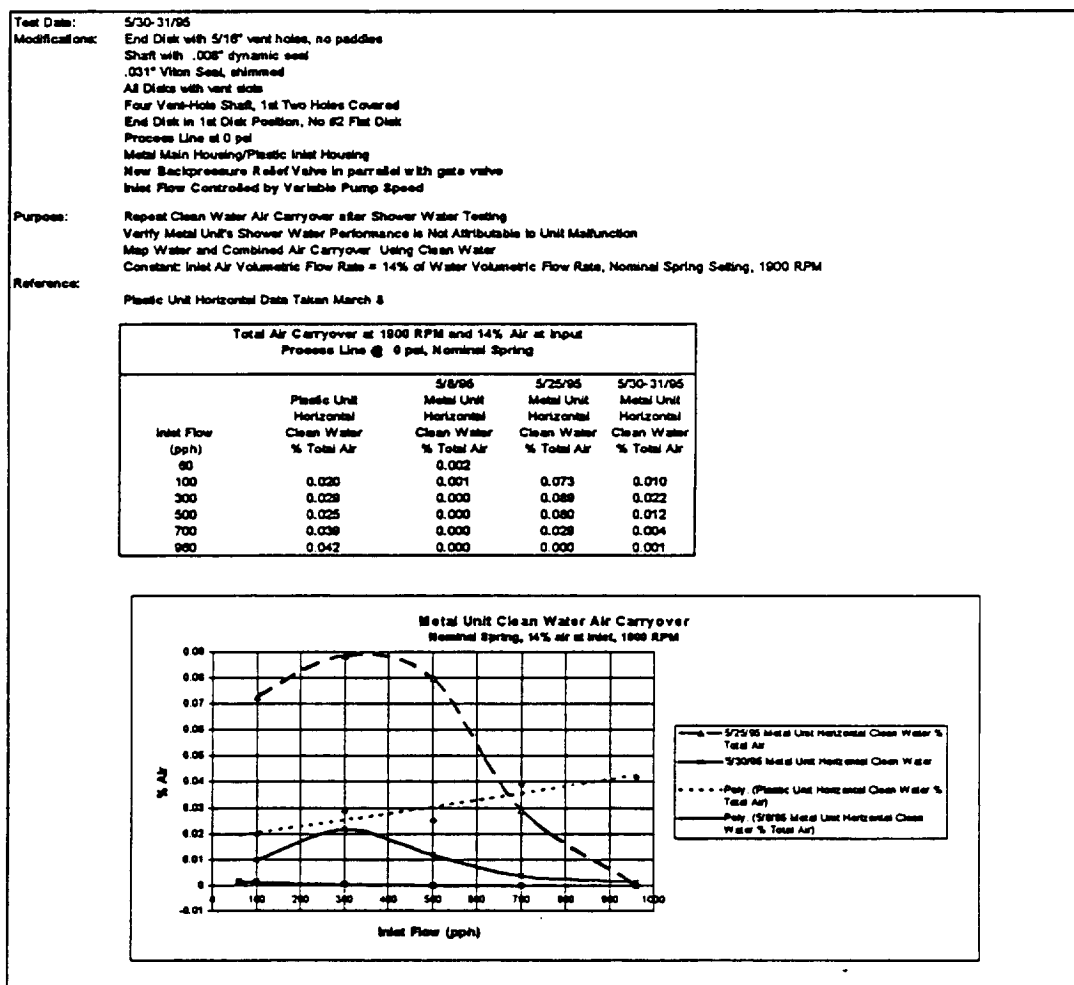


Figure 6-23

Although this improvement would suggest that something had indeed been wrong with the MLS unit, it is important to note that during the course of this test a third valve was used to regulate the backpressure. This was a 1/2 inch ball valve that had been put in the water outlet line downstream of the two valves previously being used in parallel. This is shown schematically in Figure 6-24. The ball valve had not been originally installed in the test rig to regulate backpressure, but was found to yield better results when used to do so during this last test. The gate valve was left fully open. Visual observation revealed less air present within the MLS. To verify that it was the use of this ball valve that yielded the performance improvement, some data points were again taken using the two parallel valves. The resulting air carryover was a duplicate of that seen previously (before the MLS was disassembled and “fixed”).

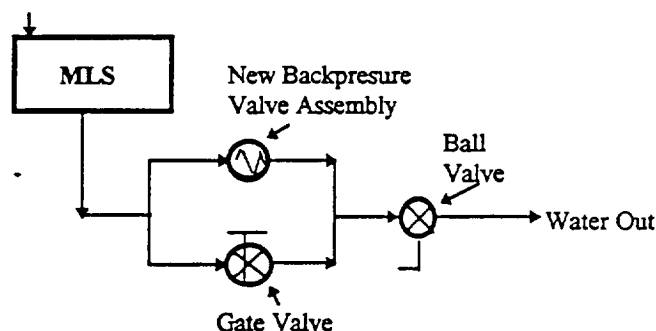


Figure 6-24: Location of Ball Valve

These realities suggested that using the two valves in parallel to regulate backpressure may have been a contributing factor in causing unstable operation and unacceptable air carryover performance.

The test rig was again filled with shower water and performance maps of air carryover made in both the horizontal and vertical orientations using the single ball valve to regulate backpressure. The results are shown in Figure 6-25 (Horizontal) and Figure 6-26 (Vertical). The results were very good: the horizontal orientation performance exceeded that of the plastic MLS, and matched it in the vertical orientation. The only exception was for 960 pph inlet flow in the vertical orientation, which clearly was producing a lot of air carryover. Repeated attempts to correct this failed, and it was decided to proceed to the Extended Performance portion of the test rather than explore this anomaly further.

Test Date: 8/1/95
Modifications: End Disk with 5/16" vent holes, no paddles
 Shaft with .008" dynamic seal
 .031" Viton Seal, shimmed
 All Disks with vent slots
 Four Vent-Hole Shaft, 1st Two Holes Covered
 End Disk in 1st Disk Position, No #2 Flat Disk
 Process Line at 0 psi
 Metal Main Housing/Plastic Inlet Housing
 New Clark Backpressure Relief Valve in parallel with gate valve
 Inlet Flow Regulated By Pump Speed (No Bypass)
 Backpressure Regulated By Globe Valve (downstream of Clark/gate valve)

Purpose: Verify Metal Unit's Performance By Comparing To Plastic Unit
 Map Combined Air Carryover Using Shower Water
 Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Plastic Unit Horizontal Orientation Shower Water Data Taken April 5
 "Old" Metal Unit Horizontal Shower Water Data Taken May 18-19

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring			
Inlet Flow (pph)	Plastic Unit Horizontal Shower Water % Total Air	5/18-19/95 Metal Unit Horizontal Shower Water % Total Air	8/1/95 Metal Unit Horizontal Shower Water % Total Air
80	0.118	0.154	0.022
100	0.023	0.847	0.008
200	0.172	0.901	0.033
300	0.112	0.714	0.022
500	0.080	0.333	0.028
600	0.018	0.316	0.023
700	0.010	0.057	0.029
980	0.021	0.029	0.021

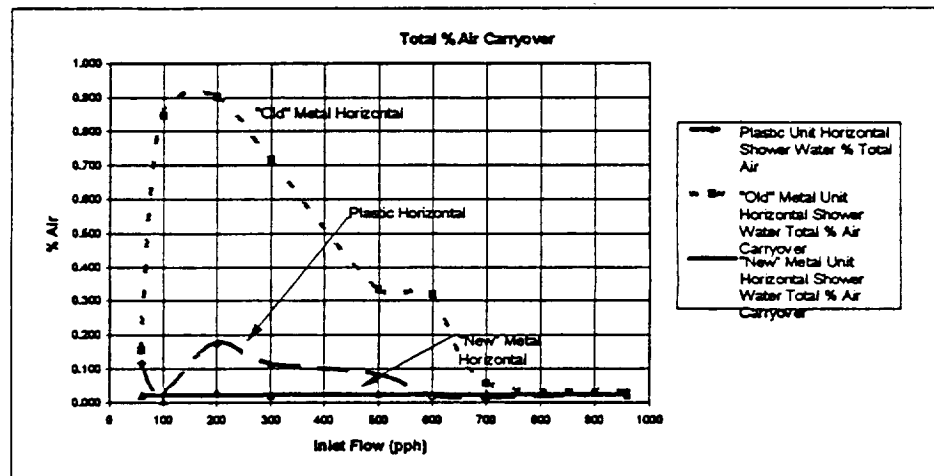


Figure 6-25: Final Metal MLS Horizontal Orientation Air Carryover

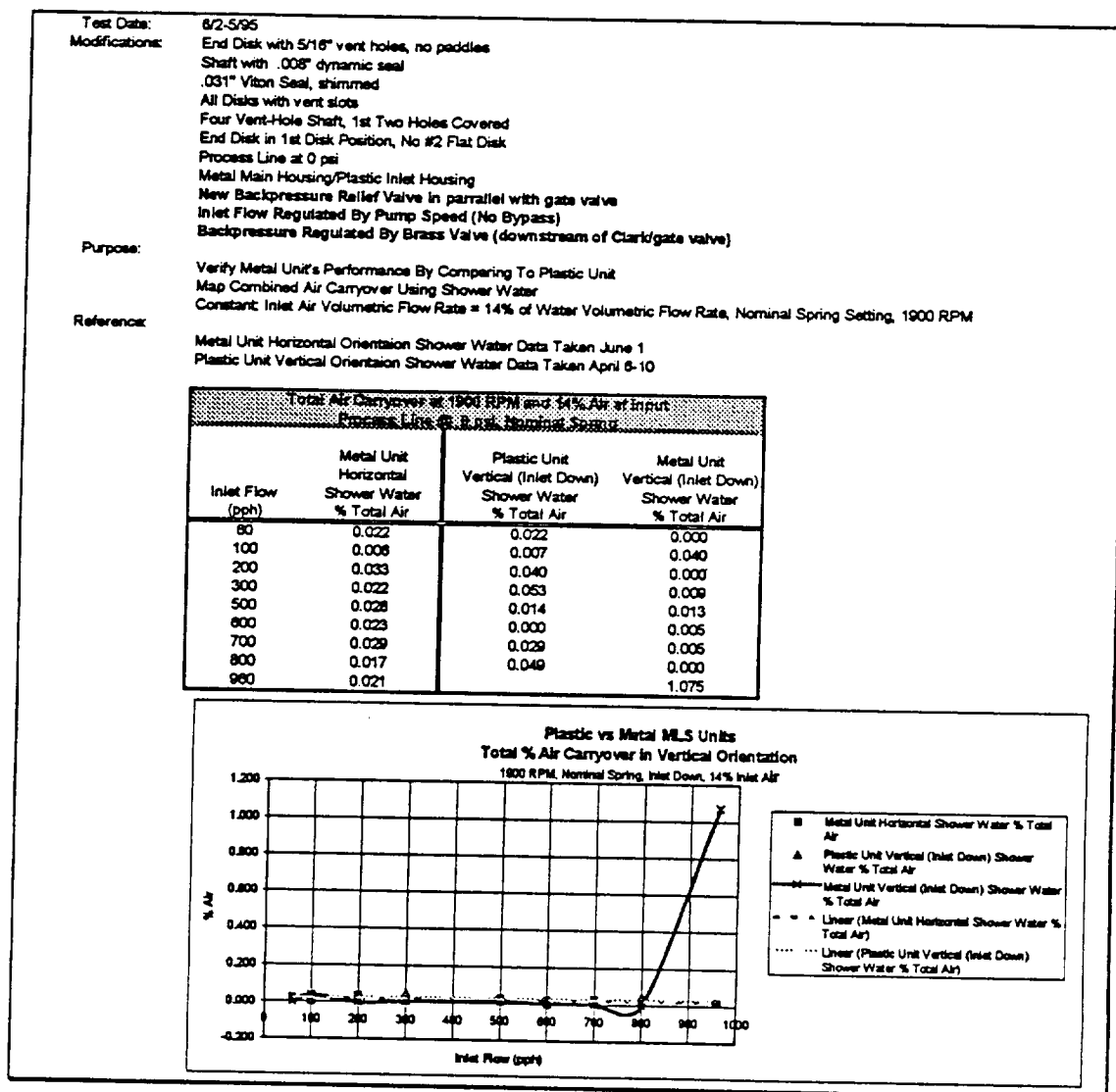


Figure 6-26: Final Metal MLS Vertical Orientation Air Carryover

CONCLUSIONS REACHED AT THAT TIME:

- The air primarily vented at discrete times, rather than continuously. During venting, the backpressure would momentarily go to 0 psi, and the depth of the water ring would consequently increase. The RPM would then slow in response to the increasing water ring depth. The interaction of each of these responses resulted in the relative instability seen in the operation of the MLS unit, and this instability affected the air carryover performance. It was therefore concluded that air carryover performance would be improved by maintaining a stable backpressure.
- Although the MLS was designed with the intention of having a constant speed motor, a variable speed motor was not used for testing under this contract. Because of the

aforementioned interaction of motor speed, water ring height and gas venting, it was concluded that the operation of the MLS would be more stable if a constant speed motor was used.

- Controlling water flow by varying the pump speed instead of using water bypass could not conclusively be shown to produce improvements in air carryover.
- Replacing the check valve with the new P/N SVSK121970-1 Backpressure Valve Assembly (see Figure 6-20: New Backpressure Valve in Parallel with Gate Valve) did not improve air carryover performance.
- Use of a single 1/2 inch ball valve to regulate backpressure (see Figure 6-24: Location of Ball Valve) resulted in dramatic improvement in the air carryover performance.
- The use of the two valves in parallel to regulate backpressure was contributing to the unacceptable air carryover performance of the MLS.

6.4.5 TEST PERIOD: June 7, 1995 - July 6, 1995, Metal MLS Extended Performance Testing

SUMMARY:

Initiated the Extended Performance Test of metal MLS unit. Backpressure was regulated by the new backpressure valve assembly. Inlet flow was held at 60 pph, inlet air was held at 14% and the MLS run at 1900 RPM. Testing frequently ran 24 hrs/day. A total of 296.5 hours was accumulated in the Extended Performance Test. No difficulties or unusual conditions were noted.

6.4.6 TEST PERIOD: July 7, 1995 - July 11, 1995, Metal MLS Post-Test Performance Mapping

Summary:

As defined in the Extended Performance Plan of Test, the metal MLS unit was performance mapped at the conclusion of the test to document any changes that may have occurred as a result of prolonged operation with shower water.

No changes were noted in the water carryover, horizontal-orientation nor in the vertical-orientation air carryover performance as shown in Figure 6-27: Post-Extended Performance Test Water Carryover Performance, Figure 6-28 and Figure 6-29, respectively. When mapping the vertical-orientation air carryover at 960 pph inlet flow, excessive air carryover was noted. This condition was also noted in the pre-test performance maps (see Figure 6-26: Final Metal MLS Vertical Orientation Air Carryover). No point is plotted at this condition as no reasonable results could be obtained.

Test Date: 7/10/95

Modifications:

- End Disk with 5/16" vent holes, no paddles
- Shaft with .008" dynamic seal
- .031" Viton Seal, shimmed
- 1.25 psi backpressure check valve in parallel with gate valve
- All Disks with vent slots
- Four Vent-Hole Shaft, 1st Two Holes Covered
- End Disk in 1st Disk Position, No #2 Flat Disk
- Process Line at 0 psi
- Metal Main Housing/Plastic Inlet Housing
- New Clark Backpressure Relief Valve in parallel with gate valve
- Inlet Flow Regulated By Pump Speed (No Bypass)
- Backpressure Regulated By 1/2 inch Brass Valve (downstream of Clark/gate valve)

Purpose: Post Extended Performance Test
Verify Metal Unit's Performance is Unchanged By Comparing To Pre-Extended Performance Test Data
Map Water Carryover Using Shower Water
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting

Reference: Pre-Extended Performance Test Data Taken May 16-17

Inlet Flow	RPM at Which Water Carryover Occurs Nominal Spring, 14% Air at Inlet					
	50	100	300	500	700	950
Pre-Extended Performance Test	1122	1162	1226	1316	1425	1656
Post-Extended Performance Test	975	1006	1087	1136	1305	1458

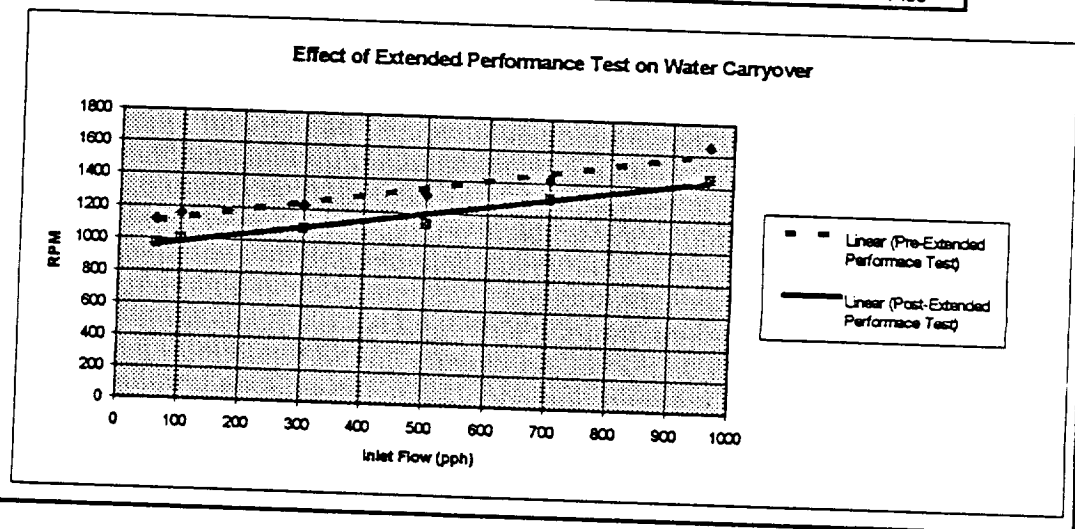


Figure 6-27: Post-Extended Performance Test Water Carryover Performance

Test Date: 7/11/95
 Modifications: End Disk with 5/16" vent holes, no paddles
 Shaft with .008" dynamic seal
 .031" Viton Seal, shimmed
 1.25 psi backpressure check valve in parallel with gate valve
 All Disks with vent slots
 Four Vent-Hole Shaft, 1st Two Holes Covered
 End Disk in 1st Disk Position, No #2 Flat Disk
 Process Line at 0 psi
 Metal Main Housing/Plastic Inlet Housing
 New Clark Backpressure Relief Valve in parallel with gate valve
 Inlet Flow Regulated By Pump Speed (No Bypass)
 Backpressure Regulated By 1/2 Inch Brass Valve (downstream of Clark/gate valve)

Purpose: Post Extended Performance Test
 Verify Metal Unit's Performance is Unchanged By Comparing To Pre-Extended Performance Test Data
 Map Vertical (Inlet Down) Air Carryover Using Shower Water
 Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Pre-Extended Performance Test Data Taken 6/2-5/95

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring		
Inlet Flow (pph)	Pre-Test Metal Unit Vertical Shower Water % Total Air	Post-Test Metal Unit Vertical Shower Water % Total Air
60	0.000	0.000
100	0.040	0.013
300	0.009	0.000
500	0.013	0.000
700	0.005	0.000
960	1.075	Unobtainable

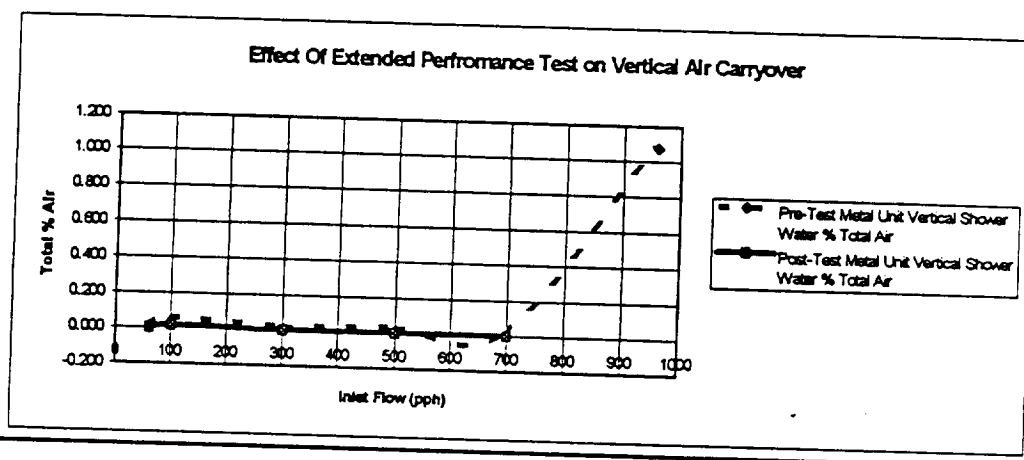


Figure 6-28: Post-Extended Performance Test Vertical Orientation (Inlet Down) Air Carryover Performance

Test Date: 7/10/95
Modifications: End Disk with 5/16" vent holes, no paddles
Shaft with .008" dynamic seal
.031" Viton Seal, shimmed
1.25 psi backpressure check valve in parallel with gate valve
All Disks with vent slots
Four Vent-Hole Shaft, 1st Two Holes Covered
End Disk in 1st Disk Position, No #2 Flat Disk
Process Line at 0 psi
Metal Main Housing/Plastic Inlet Housing
New Clark Backpressure Relief Valve in parallel with gate valve
Inlet Flow Regulated By Pump Speed (No Bypass)
Backpressure Regulated By 1/2 Inch Brass Valve (downstream of Clark/gate valve)

Purpose: Post Extended Performance Test
Verify Metal Unit's Performance is Unchanged By Comparing To Pre-Extended Performance Test Data
Map Horizontal Air Carryover Using Shower Water
Constant: Inlet Air Volumetric Flow Rate = 14% of Water Volumetric Flow Rate, Nominal Spring Setting, 1900 RPM

Reference: Pre-Extended Performance Test Data Taken 6/1/95

Total Air Carryover at 1900 RPM and 14% Air at Input Process Line @ 0 psi, Nominal Spring		
Inlet Flow (pph)	Pre-Test Metal Unit Horizontal Shower Water % Total Air	Post-Test Metal Unit Horizontal Shower Water % Total Air
60	0.022	0.000
100	0.006	0.000
200	0.033	
300	0.022	0.004
500	0.028	0.007
600	0.023	
700	0.029	0.005
960	0.021	0.004

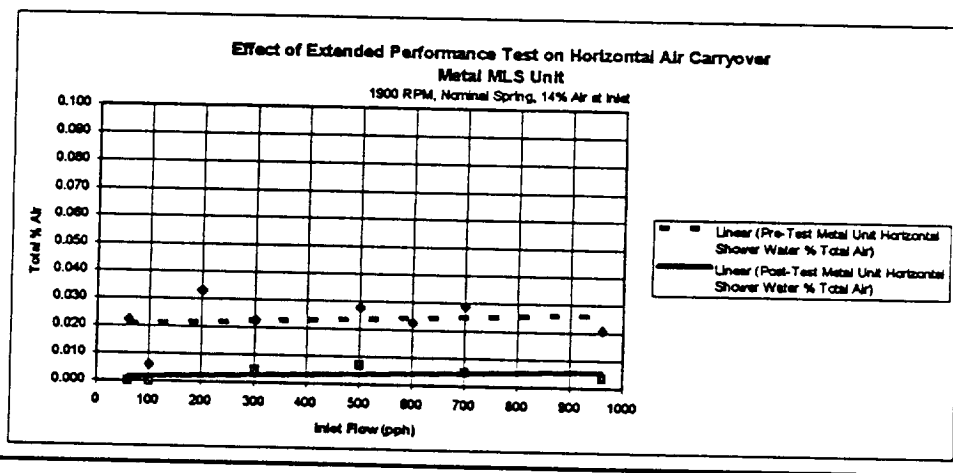


Figure 6-29: Post-Extended Performance Test Horizontal-Orientation Air Carryover Performance

CONCLUSIONS REACHED AT THAT TIME:

- After operating for approximately 300 hours in a shower water environment, the performance characteristics of the metal MLS unit were unchanged.
- The metal MLS unit was unable to provide adequate air/water separation when oriented vertically (inlet down) for the 960 pph, 14% inlet air case.

7. Observations and Conclusions

7.1 Observations

Final observations concerning the modifications made to the MLS hardware are:

- The Diaphragm Seal needs to be flat and require minimal force to seal. A .031 inch thick Fluoroelastomer seal was used.
- The SVSK120987-1 End Disk, with paddles removed and enlarged vent holes, improved the air carryover performance.
- A dynamic seal was necessary to prevent water leakage past the Rulon journal bearing.
- The flat disks, with vent holes modified into slots to reduce the air flow restriction, improved air carryover performance.
- The inclusion of an End Disk in the first or second disk position (nearest the inlet) improved performance.
- Repositioning the disk assembly shaft's vent holes two positions further away from the inlet improved water carryover performance.
- The new backpressure valve did not provide a constant backpressure that was independent of inlet flow.
- The current fault detection magnets and proximity switches did not provide the necessary sensitivity for proper operation.
- The air primarily vented at discrete times, rather than continuously. When this occurred, the backpressure would momentarily go to 0 psi, and the depth of the water ring would increase as the gas was vented. The RPM would consequently change in response to the changing depth of the water ring. It was concluded that the interaction of each of these responses resulted in the relative instability seen at times in the operation of the MLS unit, and that this instability affected the air carryover performance. Consequently, it was concluded that transient backpressure fluctuations need to be minimized or eliminated and that the backpressure needs to be held constant for all inlet flow rates.
- Use of a single 1/2 inch ball valve to regulate backpressure (see Figure 6-24: Location of Ball Valve) resulted in dramatic improvement in the air carryover performance.
- It was concluded that the use of the two valves in parallel to regulate backpressure was contributing to the unacceptable air carryover performance of the MLS.
- The diameter of the main water outlet line may need to be increased to help ensure that backpressure can be independent of inlet flow.
- The use of a translucent plastic housing was a significant aid in testing.

7.2 Conclusions

The following conclusions are made regarding the performance of the MLS:

- The performance of both MLS units met the design requirements.
- No performance degradation was noted after an extended-duration performance evaluation.
- Higher flow rates required a higher RPM to prevent water carryover.
- The percentage of air that is carried over into the water outlet lines increases with increasing RPM and inlet flow.
- 1900 RPM is an acceptable operating speed.
- The inlet chamber and P/N SVSK121960-1 Inlet Disks both affected air carryover performance when the MLS was oriented horizontally.
- Backpressure instability will adversely affect air carryover performance.

8. Recommendations

The current MLS development program successfully demonstrated the ability to meet the ISS WP requirements when operating at 1900 RPM for any water condition with 0% – 14% air in the inlet stream. Although the MLS meets or exceeds the basic performance requirements, some of its capabilities remain untested, and some others require further development. An envisioned 15 to 18 month program to continue development is therefore recommended to further advance the design concept and conduct extended performance evaluations.

The following are specific recommendations for additional development efforts for the Water Processor (WP) MLS:

Design Recommendations:

- Eliminate or improve the shaft-end seal at the air outlet. Primary consideration will be given to a redesign of the shaft geometry.
- Improve operation of the fault detection piston.
- Optimize disk spacing and sizing.
- Improve the air vent solenoid.
- Investigate the use of alternative pre-swirl mechanisms (i.e.: active and passive).
- Investigate the placement, sizing and orientation of both air and water outlet ports
- Reduce the effects of back pressure variations on performance.

Fabrication Recommendations:

- 1 plastic MLS unit with alternative configuration components, to be used for development testing.
- 1 metal MLS unit for extended performance testing
- Spare components.
- It is recommended that the fabrication of the metal MLS be delayed until the proposed design improvements are validated in development testing.

Test Recommendations:

- Evaluate design improvements.
- Use a constant speed motor for improved speed control.
- Optimize the MLS backpressure valve.
- Conduct extended performance tests using real waste waters.

9. Appendix I: MLS Mini-Specification

MINI SPECIFICATION FOR THE WATER PROCESSOR (WP) MOSTLY LIQUID SEPARATOR (MLS)

Purpose:

The purpose of this mini specification is to define the requirements for the next generation prototype MLS. This separator's continued development is on a research and development contract from Ion Electronics and therefore the requirements listed are seen as design goals to be achieved through best efforts.

Item Name: Mostly Liquid Separator

Item Number: 4703, reference WP schematic SVSK116064

Description: Free gas separator with a direct drive motor, air outlet solenoid valve, level sensing control and a speed sensor.

Function: Separate the free gas from the WP inlet waste water.

Interfaces:

Mechanical - 1/2" lines (Water inlet & outlet - high flow)

- 1/4" line (Water outlet - low flow, 15-16.8pph)

Electrical - 24 vdc

Fluid (1) -

Media

Temperature

System Inlet water press

MLS Outlet water press

Max operating pressure

Max. particle size

pH

TOC

Internal

Waste Water & gasses

65 to 113 F

0 to 10 psig

.5 to 10 psig

10 psig

100 m

5-8

250

External

air

65 to 113 F

N/A

N/A

14.7+/-2 psia

N/A

N/A

N/A

Performance Goals:

Inlet free gas (2)

0% to 100% min/max

0% to 14% average

MLS Inlet water flow rate

0 - 963 pph

Outlet water flow rate

15 to 16.8 pph to process pump, balance to tank

Carryover

0.4% gas in water outlet

0.0% water in gas outlet

Proof pressure

20 psig

Burst pressure

40 psig

Separator speed

0 - TBD rpm

Operation characteristics

Orientation

as a design goal the MLS operate in any 1g & 0g orientation

Start up

full of water or empty

Life

87600 hrs as a design goal

Configuration:

Diaphragm seal	Shall be designed so as to not be over stressed
Delta pressure sensing	Delta p ports shall be provided for external sensing and separator operation

Leakage: No visible leakage or damage is allowed when exposed to proof pressure for a minimum of five minutes.

Power consumption: No requirement, but power should be minimized.
(reference flight requirement = 30watts max, 10 watts nominal)

Size & weight: TBD

Notes:

1. Refer to attachment I (Boeing Envelope Drawing 683-10019 Rev D, Table IV) for complete waste water model definition.
2. Assumption: Volumetric flow rate of the air = Vol of water

10. Appendix II: MLS Plan of Test



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REVISION: Basic
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DATA RIGHTS N

TPION - 02

**SPACE STATION WATER PROCESSOR
MOSTLY LIQUID SEPARATOR
(MLS)**

TEST PLAN

CONTRACT # NAS8-38250-12

Prepared for
**ION ELECTRONICS
6767 MADISON PIKE
HUNTSVILLE, AL 35806**

Date issued
September 1994

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10.1 Introduction:

This test plan has been generated to evaluate the improvements, developed under this contract, to the Space Station Water Processor (WP) Mostly Liquid Separator (MLS). The MLS, item 4703, is an integral component in the Waste Water Orbital Replacement Unit (WWORU) of the WP. The WWORU schematic is shown in Figure 1.0-1. This ORU is responsible for receiving, degassing, and storage of the Space Station waste water as well as it provides the system flow and pressure. The MLS is responsible for removing the free gas from the waste water. This separator must be capable of handling up to 900 pph inlet flow rate.

This test plan defines the tests necessary to evaluate two new MLSs. One of these will be fabricated from a clear plastic material, polysulfone, for assistance in visual operation checks and the other will be fabricated from flight capable materials. Parts for a third MLS will be available as spares or for use in future programs. The two assembled prototype units will be evaluated to verify the MLS's capability at a variety of operating conditions including different inlet water and air flow rates.

The MLS evaluation will be conducted at Hamilton Standard Space Systems International's, HSSSI, Engineering Laboratory facilities.

The MLS is covered under US Patent # 5,244,479 titled Liquid/Gas Separator For Soapy Liquid dated Sept. 14, 1993.

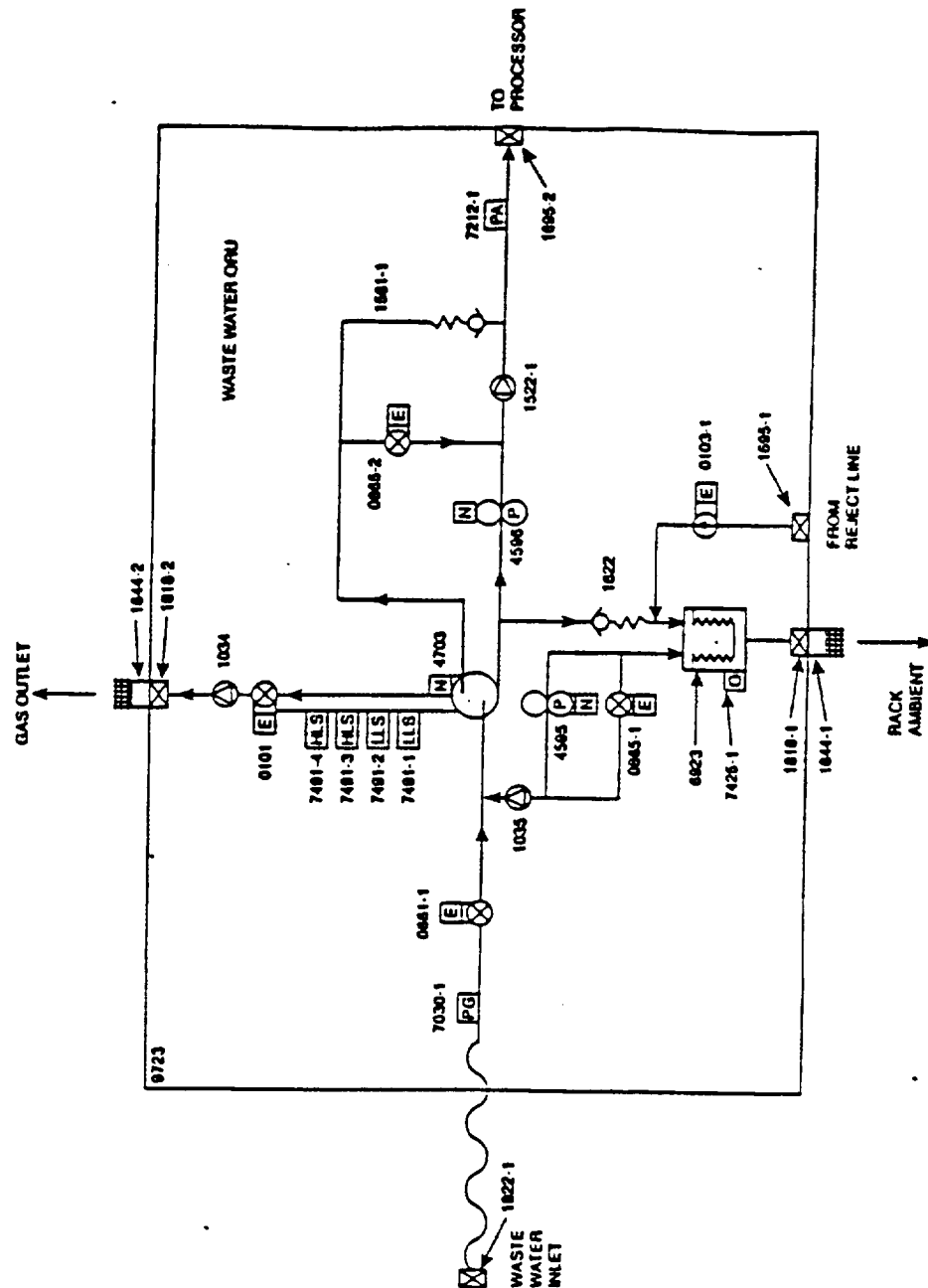


Figure 10-1: Water Processor Waste Water ORU

10.2 Background:

The MLS in the WP, along with all the other WWORU components, must be capable of surviving the harsh environment inherent in the waste water stream. In addition, the MLS must have an operational life of ten years. As a result of these significant challenges for the MLS design, a development program was conducted at HSSSI as part of the Space Station Program.

A prototype MLS was originally developed for the Space Station Potable Water Processor (PWP). This MLS concept was designed and fabricated to handle the water conditions of the PWP. The major PWP requirements included separating condensate waste water and air at the maximum inlet flowrate of 240 pph. This prototype MLS went through some evolution in its separation technique. Some of the evolution was the result of the Space Station configuration changing to a combined Water Processor (WP). The final developed concept incorporated a series of thin rotating disks which provided the centrifugal force needed for the air/water separation.

This prototype, in its various configurations, was evaluated at HSSSI from the second quarter 1990 to third quarter 1992.

The results from this prototype indicated that the separator was performing with acceptable results in the air/water separation but that the control mechanism in the MLS required improvements to handle the WP conditions. Also the next generation separator will require increased capacity in order to handle the larger inlet flow rate of 900 pph for the WP.

10.3 Test Description:

The following sections identify the test objectives and the test program schedule.

10.3.1 Test Objectives:

The MLS test plan contains four objectives. The primary objective of the testing will be to map the performance of the MLS within the expected operating conditions of the Space Station Water Processor.

A second objective of the MLS testing is to demonstrate the insensitivity of the MLS to gravity, thereby demonstrating operability in a microgravity environment. The insensitivity of the design to gravity will be demonstrated by reproducing test results in three different orientations while operating in a 1-g environment.

The third objective of the testing will be to identify potential enhancements to the design or operation of the MLS. These enhancements may take the form of operating changes or physical adjustments of the hardware.

The fourth objective of the MLS testing will evaluate the life characteristics of the metal separator. This testing will only be performed as schedule time permits at the conclusion of the performance testing. Therefore the duration of this test is expected to only last several weeks.

Note: Do to the complexity of the test program it may be necessary to alter the test plan during testing based on the results obtained. If this occurs, the document will be redlined and Ion Electronics and NASA will be notified prior to conducting the red-lined test.

10.4 Test Schedule:

The test program schedule is attached in Figure 3-1. The test program has been divided into three phases for each of the two separators. The plastic separator will be tested first followed by the metal separator. This will make it possible to incorporate information learned from the assembly and operation of the plastic MLS into the construction and testing of the metal separator.

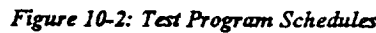
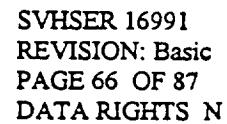
The first phase of the test program for each MLS consists of the setup/checkout test. This phase will verify individual operation of both the mechanical and electromechanical components within the separator. This checkout/setup will verify the proper assembly of the MLS assembly, limit switch and solenoid valve operation and overall MLS operation.

The next phase of each MLSs testing will consist of performance testing. The performance tests will be divided into three stages. The first stage of the performance test will use distilled water and air to map the MLS performance at a wide variety of liquid and gas flow rates. This performance testing will also be evaluating MLS performance versus rotational speed. Therefore this first stage of the performance mapping will be done with the MLS operating between 800 and 1500 rpm.

The second stage of the performance test will duplicate many of the test points from stage 1 but with a change in the liquid phase composition. Instead of using the distilled water of stage 1, stage 2 will use a mixture of distilled water and virgin Igepon soap. Virgin soap and water mixtures maximize the generation of soap foam. Therefore, it is anticipated that this stage will create the most difficult challenge for separator based on the previous prototype tests.

The third stage of the performance mapping will also repeat many of the test points from stage 1 and 2 but will rely on a real waste water stream combined with air to challenge the MLS.

The third phase of testing will differ for each separator. The plastic MLS will be used to evaluate sensitivity to zero gravity performance while the metal MLS will be life tested on a real waste water solution.



The MLS effectiveness will be monitored throughout the checkout test. Effectiveness will be evaluated based on two preeminent criteria. The first criteria measures liquid carryover in the MLS gas vent. The second criteria will monitor gas carryover through the liquid effluent lines. A quantitative assessment of these two criteria will provide an objective measurement of MLS performance at the different steady-state flow conditions of the checkout test.



Table 10-1: Checkout Test Verification List

STEP	TEST
1. MLS Assembly	1. Proper Assembly, No Drag 2. Motor Separator Alignment OK, Coupling OK 3. Proper Motor Rotation 4. Speed (800-3000 RPM) Operation
2. Proof Pressure	1. Perform proof pressure test to 20 psig, no damage allowed after 5 minute exposure
3. Speed Set	Requirement: Determine the minimum RPM which at which no H ₂ O is carried over in the gas vent for 3 control piston spring settings (min., med & max.) and several gas and liquid flow rates. 1. Vary RPM from 1500 to 800 at each of the spring settings. 2. Select min. RPM & spring setting.
4. Speed Check	Requirement: Verify at selected spring setting and several gas and liquid flow rates that gas carry-over into the water outlet is 0.4% or less. 1. Vary RPM from 800 to 1500 and check for gas in water outlet 2. Reselect min. RPM if necessary (rerun step 3 if required)
5. Vertical Mount Operating Check	1. Control piston up, verify operation with water flow at 60 pph and 7% gas 2. Control piston down, verify operation with water flow at 60 pph and 7% gas
6. Low Level, High Level Limit Switch Checkout	1. Set limit switches to operate within the proper range 2. Verify solenoid valves operate in conjunction with limit switches
7. MLS Full & Empty Start up	1. Verify startup with no liquid flow 2. Verify startup flooded with water and no gas flow

10.6 Performance Test, Both Separators

Performance verification of the MLS will consist of monitoring separator performance at a series of operating conditions. This section consists of three stages which include operation on clean water, virgin soap and then real waste water.

10.6.1 STAGE 1, Clean Water

The first stage of the performance test will use a distilled water and air mixture to map the effectiveness of the separator. Table 4.2-1 lists the steady state liquid and gas flow rates to be tested during this stage. The test schematic that will be used throughout the performance test which is designed to closely simulate operation within the waste water processor is shown in Figure 4-2.



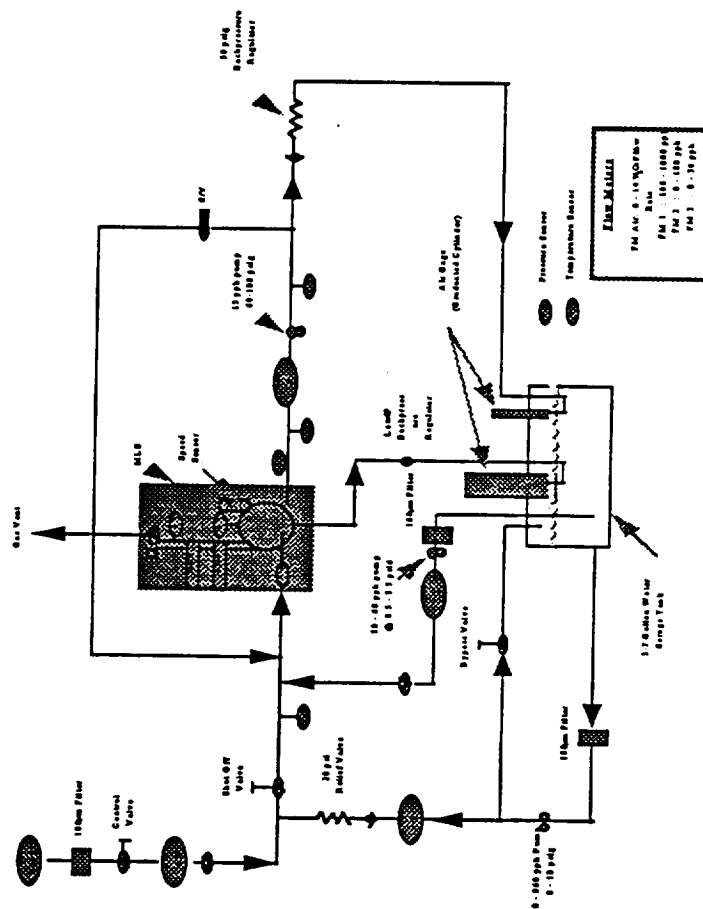
After mapping the steady-state flow conditions, the performance testing will investigate the separator's effectiveness while operating through transient conditions. These test will transition from low to high liquid flow in rapid fashion (<5 seconds), operate briefly at the high flow (~ 5 minutes) and return to the low liquid flow rates. Table 4-3 details the transient fluid flows to be tested.

Table 10-2: Performance Test Conditions Steady State Fluid Flow

<i>liquid flow (pph)</i>	<i>gas flow (volume % of liquid flow)</i>				
	0	2%	6%	10%	14%
—					
60					
100					
500					
960					

Table 10-3: Performance Test Conditions Transient Fluid Flow

<i>liquid flow (pph)</i>	<i>2% Air</i>	<i>14% Air</i>
60 to 100 to 60		
60 to 960 to 60		



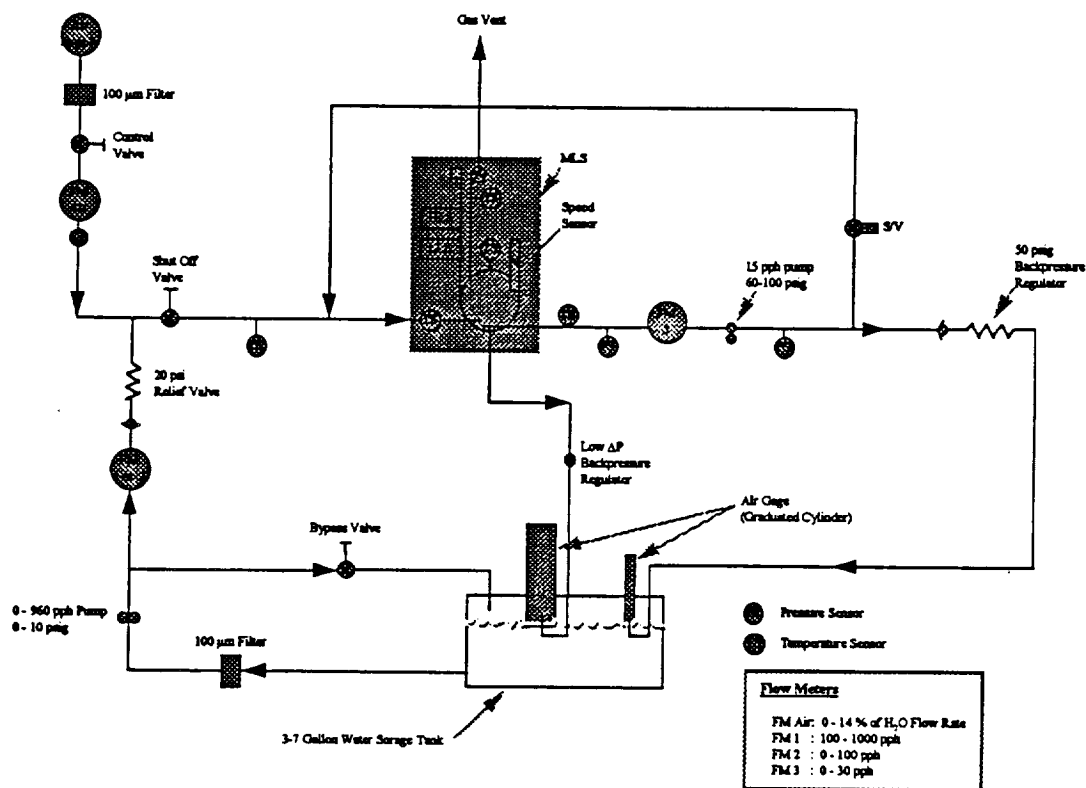


Figure 10-4: Performance/Life Test Schematic

10.6.2 STAGE 2, Virgin Igepon Soap

During the stage 2 testing the liquid phase will use a mixture of distilled water and virgin Igepon soap. The concentration of the soap is .425 gm/pound water (identical to the soap/water ratio in handwash and showers). The Igepon soap composition is defined in Table 4.5-2. The first step in the stage 2 testing will be a repeat of the speed check from the checkout test (Table 4-1, step 4). Following the speed check the second stage of the performance test will duplicate the test points from the stage 1 performance test (Table 4-2).

The second stage performance test will also duplicate the transition flow test completed at the end of stage 1. These tests will repeat the conditions listed in Table 4-3 but will use the distilled water, virgin soap, air mixture used throughout stage 2.

10.6.3 Zero Gravity Performance, Plastic MLS Only

Prior to progressing to stage 3 of the performance test the plastic housing MLS will be evaluated in two alternate orientations to verify insensitivity to the gravity vector. These alternate orientation tests will still rely on the same virgin Igepon soap mixture from stage 2. Both setups will position the rotating shaft in the vertical plane. The first orientation will operate with the inlet port below the separator (1e: control piston up). The second orientation will operate with the inlet port above the separator (1e: control piston down). Table 4-4 lists the steady state operating conditions for the two orientations. Table 4-5 lists the transient tests that will be performed in the two orientations.

*Table 10-4: Performance Test Conditions
Steady State Fluid Flow
Alternate Orientation*

liquid flow (gph)	air flow (volume % of liquid flow)				
—	0%	2%	6%	10%	14%
60					
960					

*Table 10-5: Performance Test Conditions Transient Fluid Flow
Alternate Orientation*

liquid flow (gph)	2% Air	14% Air
60 to 100 to 60		
60 to 960 to 60		

10.6.4 STAGE 3, Real Waste Water

Throughout all of the stage 3 testing the liquid phase will consist of real waste water as defined in section 4.4. The first step in the stage 3 testing will also repeat the speed check from the checkout test (Table 4-1, step 4). Next, the stage 3 performance test will then repeat the test points of stage 1 & 2. Table 4-2 lists the steady-state and Table 4-3 lists the transient liquid and gas flow rates to be tested.

10.7 Life Testing, Metal MLS Only

The life testing will be performed as time allows and will be performed after the checkout and performance mapping on the Metal MLS unit 2. The duration of the life testing will be determined by the remaining schedule available at the end of the checkout and performance tests. The unit will be disassembled and inspected after the test. Any signs of wear, corrosion and contamination will be recorded.

The operating conditions for the test will be as follows:

1. Waste Water as defined in section 4.4
2. Liquid flow rate of 60 gph
3. Gas flow at 7% of liquid volumetric flow
4. Operating time to be 24 hours per day, 7 days per week

4.4 MLS Life Test Waste Water Definition

The waste water to be used for the life testing will consist of shower, handwash, vacuum distilled urine, and mouth wash water. The actual make up of the waste water is defined in Table 4-6. Igepon soap 6503-45-4 and Crest toothpaste will be used for the testing. The Igepon soap formulation is identified in Table 4-7.

Oxone and sulfuric acid will be used to pretreat the distilled urine. The Oxone and sulfuric acid pretreat concentrations are 5.0 and 2.3 grams/liter of urine respectively. Deionized water will be used to simulate the urinal flush water. The percentage of pretreated urine to flush water is 75% and 25% respectively.

Each waste water batch will be monitored and the data recorded for TOC, TC, conductivity and Ph. This waste water will be used for both testing at HSSSI and for the suppliers life testing.

Waste Water	Space Station (lb/day)	Space Station (% Total)	Test Water (% Total)
Shower Water (Igepon 6503-45-4)	24.00	20.20	50.10
Oral Hygiene (Crest Regular Flavor Toothpaste)	3.20	2.70	2.70
Urine Distillate (Oxone/H ₂ SO ₄ Pretreat)	13.24 (4)	11.10	14.80
Urine Flush	4.40	3.70	(5)
Handwash	24.00	20.20	(1)
Fuel Cell	11.74	9.90	32.40 (3)
Wet Shave	3.52	3.00	(1)
Humidity Condensate	24.00	20.20	(2)
Samples/Checks	2.72	2.30	(2)
Wash Cloth Bath	8.00	6.70	(1)
Total	118.82	100	100

(1) This water is included in the shower water

(2) This water is included in the fuel cell water

(3) Deionized water will be used to simulate this water

(4) Pretreat with 5 grams of Oxone and 2.3 grams of sulfuric acid

(H₂SO₄) into 6.25 cc of water per liter of raw urine

(5) Mix 33.3% urine flush (DI water) into urine prior to distillation

Table 10-6: MLS Life Test Waste Water

Shower/Handwash Formulation 6503-45-4	
Ingredients	% by weight
sodium-n-coconut acid-n-methyl taurate (SCMT) (24% active)	98.75
lecipur 95-F (soybean lecithin)	0.50
luviquat FC-500 (polyquaternium 16)	0.75

Table 10-7: Igepon Soap Test Formulation

10.8 Test System/Environment:

10.8.1 Test System:

The system test schematics shown in Figure 4-1 will be used for the checkout tests to be initially conducted on each unit. The system test schematic shown in Figure 4-2 will be used for the steady state and transient performance tests to be conducted on each unit. In addition, the schematic in Figure 4-2 will be maintained for the life testing to be performed on the metal MLS at the completion of the checkout and performance testing. All of the separator testing except for section 4.2.3 will be conducted with the rotating shaft of the separator and motor oriented horizontally.

10.9 Test Environment:

All tests will be conducted at a normal ambient conditions of approximately: Temperature 70 +/- 5 F, Atmospheric Pressure 14.7 +/- 0.3 psi, Relative Humidity 30 - 80%.

11. Appendix III: MLS Extended Performance Test Plan

SPACE STATION WATER PROCESSOR MOSTLY LIQUID SEPARATOR (MLS)

Extended Performance TEST PLAN

Contract # NAS8-38250-12

*Prepared for
ION Electronics
6767 Madison Pike
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11.1 Introduction

This test plan describes the MLS Extended Performance Testing that will be performed using the metal MLS unit. Such testing is part of a larger MLS test effort, which is described in the overall MLS Test Plan, last revised in December 1994. This test plan is meant as a supplement to the overall one. The objective of this document is to define the test conditions to be used during the Extended Performance Testing. In cases where this document differs from the aforementioned MLS Test Plan, this test plan will supersede the original. The overall scope and objective of the original test plan are not affected.

The Metal MLS unit is one of two assembled prototype units that are being evaluated to verify the MLS' capabilities in a variety of operating conditions.

This additional test plan is created to take advantage of what has been learned about the operation of the plastic MLS unit thus far. In addition, it allows Extended Performance Testing to occur in parallel with continued performance testing. This will allow more time in an Extended Performance Test than originally envisioned, and will also allow time to explore some further refinement(s) to the plastic MLS unit.

As stated in the overall Test Plan, testing will be conducted at Hamilton Standard Space & Sea Systems (HSD S&SS) Advanced Engineering Laboratory.

The MLS is covered under US Patent 5,244,479 titled Liquid/Gas Separator For Soapy Liquid, dated Sept 14, 1993.

11.2 Test Description

The following sections identify the test objectives and schedule.

11.2.1 Test Objectives

The objectives of this test are a subset of those described in the overall MLS Test Plan, and are:

To verify that the performance of the Metal MLS unit is the same as that of the plastic MLS unit (described and tested per the overall MLS Test Plan).

To evaluate the endurance characteristics of the Metal MLS unit within the allowable time left for the overall MLS program. Of prime concern is the operation of the control piston and the diaphragm air-seal.

To identify any potential enhancements to the design or operation of the MLS. These enhancements may take the form of actual or recommended operating changes or physical adjustments to the hardware.

11.2.2 Test Schedule

The Metal MLS Test is divided into four phases:

The first phase will consist of the setup/checkout of the metal MLS unit. Parts needing rework to make their configuration the same as that which currently exists on the plastic MLS unit will be performed, utilizing the

information learned thus far in MLS operation and testing. This phase will verify the proper operation of both the mechanical and electromechanical components within the separator, and also of the overall assembly.

The second phase will consist of verification of the performance of the Metal MLS unit. This will consist of mapping the performance of the unit using both clean water and shower water, and comparing the results with those obtained using the plastic MLS unit under similar conditions.

The third phase will consist of the actual Extended Performance Testing of the Metal MLS unit. Testing will be performed using a low inlet flow (60-100 pph), 14% Air in the inlet flow, and shower water. This phase will continue for the maximum time allowable.

The fourth phase will consist of re-mapping the performance of the unit using shower water after the completion of the third phase, and comparing the results with those obtained in the second phase of this test. This will document any performance degradation that may have occurred, and will aid in the post-test teardown inspection and report write-up.

11.3 Test Conditions

11.3.1 Checkout

The checkout phase will confirm the proper assembly and operation of the separator. Table 3-1 lists the operational characteristics to be verified during this test phase. This phase will be conducted using the test rig used for the testing of the plastic MLS unit, shown schematically in Figure 3-1.

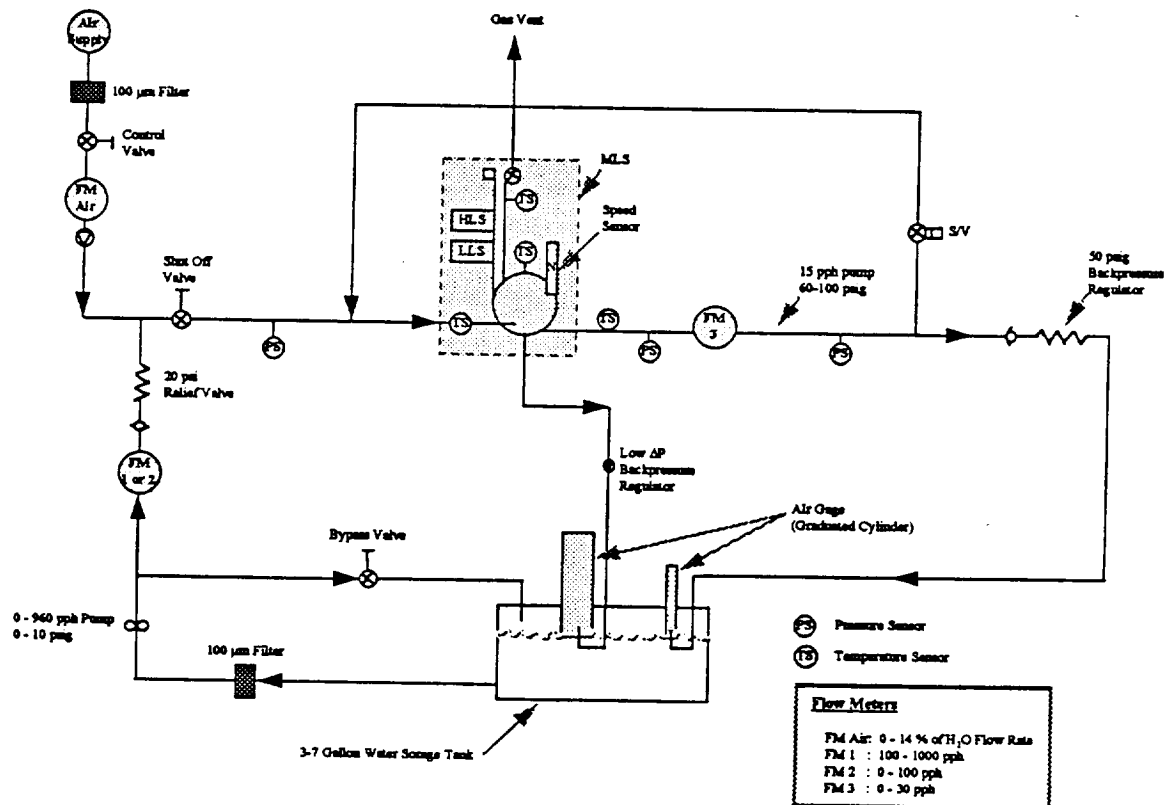
All test phases will use a 100 micron filter in the MLS inlet line. This filter will simulate space flight conditions. The MLS unit will be in a horizontal orientation for this phase.

Table 11-1

STEP	TEST
1. MLS Assembly	1. Proper assembly, No drag. 2. Motor/Separator alignment OK 3. Coupling OK 4. Proper Motor Operation (Speed, Rotation)
2. Proof Pressure	1. Perform proof pressure test to 20 PSIG, no damage allowed after 5 minute exposure at pressure.

Checkout and Verification Test-Setup Schematic

Figure 11-1





11.3.2 Verification

Verification testing of the Metal MLS' operation shall consist of obtaining similar performance maps to those obtained with the plastic MLS unit. Testing will consist of mapping separator performance at various conditions. Conditions to be varied during testing are inlet flow rate, water type and orientation of the MLS unit.

Characteristics to be mapped will be water and air carryover. Water carryover will consist of recording the minimum RPM at which water carryover occurs for a given inlet flow and water type. Air carryover shall consist of recording the percentage of air present (expressed as the volumetric flow rate of air to that of the water, in percent) in the water outlet lines, for each given inlet flow, separator orientation and water type.

11.3.2.1 Clean Water

This phase will use a distilled water and air mixture to map the effectiveness of the separator. Tables 3-2 and 3-3 list the specific tests to be performed.

Table 11-2

Water Carryover Mapping: Clean Water	
Description:	Record minimum RPM at which water carryover in gas vent line will not occur for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 %
Variant Parameters:	Inlet Flows (pph): 60 100 200 300 500 700 960

Table 11-3

Air Carryover Mapping: Clean Water	
Description:	Record Percent Air on Water outlet lines for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 % RPM: 1900
Variant Parameters:	Inlet Flows (pph): 60 100 200 300 500 700 960

11.3.2.2 Shower Water

This phase will use a shower water and air mixture to map the effectiveness of the separator. Tables 3-4 and 3-5 list the specific tests to be performed. Air carryover data will be collected with the MLS in both the Horizontal and Vertical (inlet down) orientations.

Table 11-4

Water Carryover Mapping: Shower Water	
Description:	Record minimum RPM at which water carryover in gas vent line will not occur for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 %
Variant Parameters:	Inlet Flows (pph): 60 100 200 300 500 700 960

Table 11-5

Air Carryover Mapping: Shower Water	
Description:	Record Percent Air on Water outlet lines for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 % RPM: 1900
Variant Parameters:	1. Orientation: Horizontal Vertical 2. Inlet Flows (pph): 60 100 200 300 500 700 960

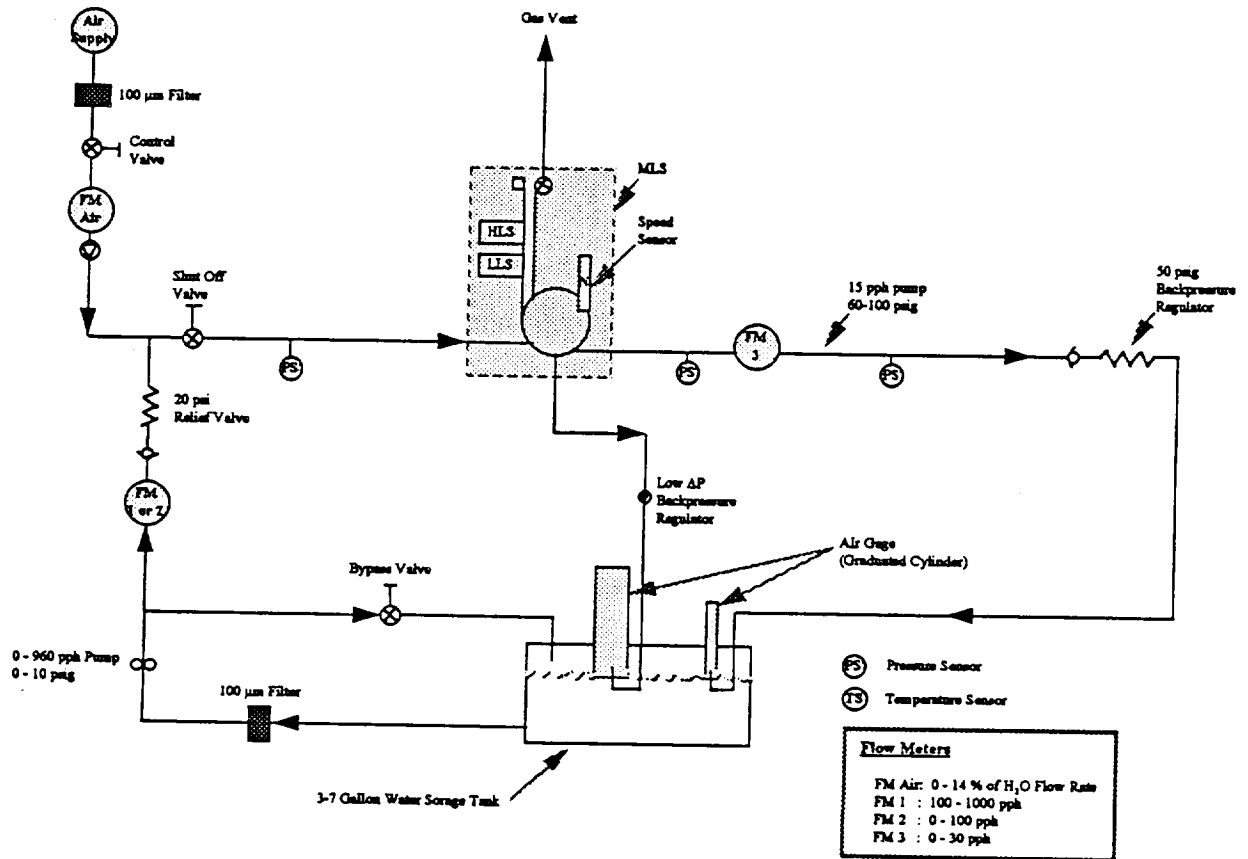
11.3.3 Extended Performance Test

The Extended Performance Test phase will be performed after the checkout and verification testing is complete, and will last for approximately one month (the actual duration will be affected by the remaining schedule left in the overall program).

This phase will run the Metal MLS in a test setup shown schematically in Figure 3-2. Testing will occur approximately nine hours per day and will occur on workdays only.

Replenishment of shower water will occur on an as needed basis.

Table 3-6 lists the specific parameters for this test phase.



Extended Performance Test-Setup Schematic

Figure 11-2

Table 11-6

Extended Performance Test	
Description:	Run Metal MLS unit for an extended duration using low flow rate shower.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 % Inlet Flow: 60-100 pph

11.3.4 Check for Performance Degradation

Once the Extended Performance Test is complete, the MLS unit will be re-mapped at various conditions using a shower water and air mixture. The results obtained will be compared with those obtained in phase two (Verification Testing). Differences seen will aid in quantifying any performance degradation the MLS unit has experienced as a result of the Extended Performance phase of the test.

Tables 3-7 and 3-8 list the specific tests to be performed. Air carryover data will be collected with the MLS in both the horizontal and vertical orientations.

Table 11-7

Post Extended Performance Water Carryover Mapping: Shower Water	
Description:	Record minimum RPM at which water carryover in gas vent line will not occur for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 %
Variant Parameters:	Inlet Flows (pph): 60 100 200 300 500 700 960

Table 11-8

Post Extended Performance Air Carryover Mapping: Shower Water	
Description:	Record percent air on water outlet lines for each inlet flow condition.
Invariant Parameters:	Orientation: Horizontal Inlet Air: 14 % RPM: 1900
Variant Parameters:	1. Orientation: Horizontal Vertical 2. Inlet Flows (pph): 60 100 200 300 500 700 960

11.4 Test System and Environment

11.4.1 Test System

The Checkout, Verification and Post-Extended Performance Test verification will be conducted on the test rig used to test the plastic MLS unit. This setup is shown schematically in Figure 3-1.

The Extended Performance test will be conducted on a second simplified rig set-up, shown schematically in Figure 3-2.

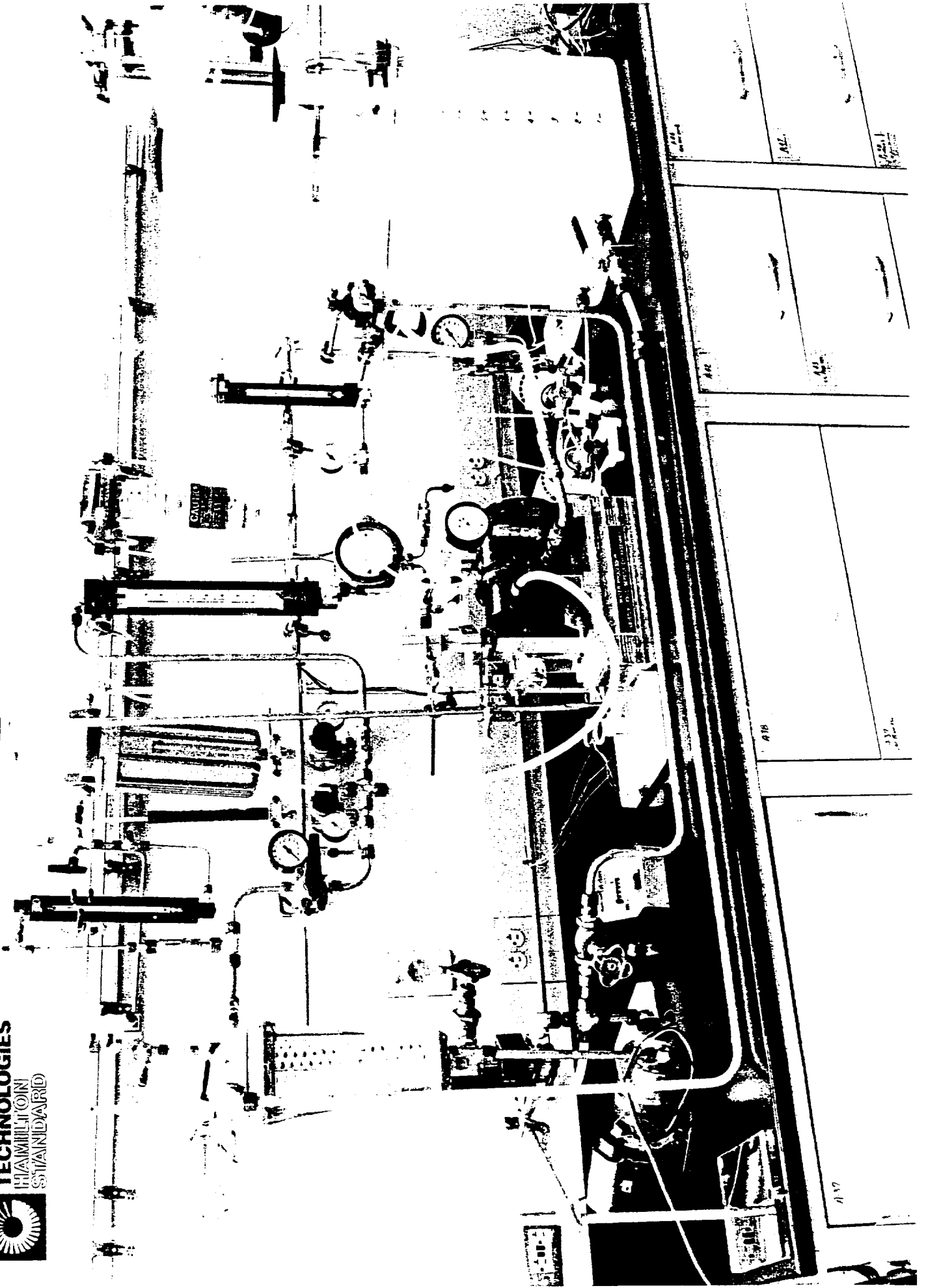
11.4.2 Test Environment

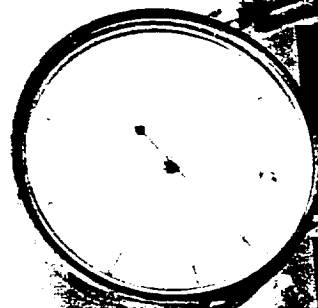
All tests will be conducted at room temperature conditions: Temperature 70 ± 5 °F, Atmospheric Pressure 14.7 ± 0.3 psi, Relative Humidity 30 - 80 % (all approximate).

12. Appendix IV: Photographs



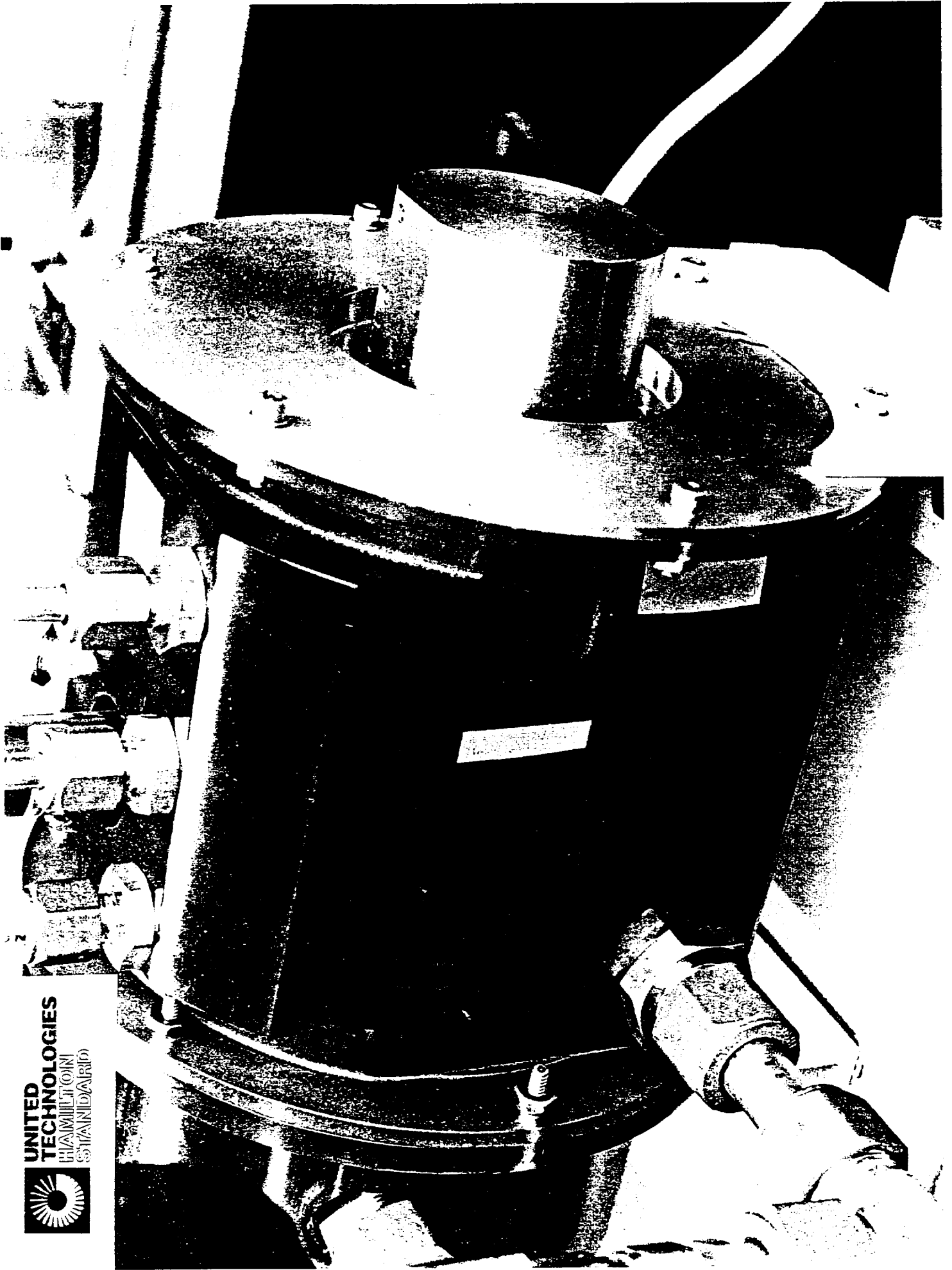
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WATER PROCESSOR
MOSTLY LIQUID SEPARATOR ASSEMBLY





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